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Perceptual And Acoustical Comparisons Of Motor Speech Practice Options For Children With Childhood Apraxia Of Speech

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PERCEPTUAL AND ACOUSTICAL COMPARISONS OF MOTOR SPEECH PRACTICE OPTIONS FOR CHILDREN WITH CHILDHOOD APRAXIA OF SPEECH

By

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PERCEPTUAL AND ACOUSTICAL COMPARISONS OF

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Children with childhood apraxia of speech (CAS) need intensive and accurate practice to establish an accurate motor plan and improve their speech production. Computer-led practice led to a greater quantity of practice and was preferred over parent-led practice. Further knowledge regarding children's accuracy of speech during independent practice is needed to determine if computer-led practice is a viable practice tool. Twelve children diagnosed with CAS, between 3-0 and 7-11 years of age, participated in speech practice during computer-led, parent-led, and clinician-led practice. Comparisons of perceptual accuracy of consonants and vowels, acoustical accuracy of stops, vowels, and fricatives, and variability of stops, vowels, and fricatives were examined.

The first study found no significant differences between perceptual accuracy of consonants and vowels during the three practice conditions. Additionally, speech productions in the computer-led condition led to greater precision in back sounds and fewer out-of-class substitutions and deletion errors compared to the parent-led and clinician-led conditions. Therefore, computer-led practice led to speech productions that were as accurate as current practice.

The second study found vowel productions were consistent across all three conditions. Production of fricatives were consistent across all three conditions, with greater accuracy in the computer- and clinician-led condition on two fricatives compared to the parent-led condition. There were no significant differences in over half of the stop productions. The computer- and clinician-led conditions led to the longest durations, which may have led to increased accuracy, while the parent-led condition led to the shortest durations. Overall, the greatest variability occurred in the parent-led condition across all manners of production, followed by the clinician-led condition, and the computer-led condition revealed the least variability. These findings suggest that computer-led practice led to speech productions that were comparable or better than clinician-led and parent-led conditions.

These studies provide evidence that computer-led speech practice is a viable practice tool for children with CAS to achieve accurate speech productions.

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CHAPTER 1 – LITERATURE REVIEW

Introduction

Children diagnosed with a speech sound disorder (SSD) that is suspected to be childhood apraxia of speech (CAS) struggle to communicate basic needs to even those closest to them. CAS leaves children with severely unintelligible speech as they struggle to develop sounds, strain to blend sounds together to form words, and cannot control the inflection of their voice, despite no muscular deficits (ASHA, 2007). Exact prevalence is unknown, however differing reports state 1-2 of every 1,000 children (Shriberg, Aram, & Kwiatkowski, 1997a) and 3.4-4.3% of speech-impaired preschoolers (Delany & Kent, 2004) have CAS. CAS is often accompanied by language and literacy deficits (ASHA, 2007; Lewis, Freebairn, Hansen, Stein, Shriberg, Iyengar, et al., 2006; Mirenda & Mathy-Laikko, 1989), academic difficulties (Lewis, Freebairn, & Taylor, 2000; Overby, Carrell, & Bernthal, 2007; Teverovsky, Bickel, & Feldman, 2009) deficits in phonological processing and literacy (Lewis, et al., 2000; Lewis, Freebairn, Hansen, Iyengar, & Taylor, 2004; McNeill, Gillon, & Dodd, 2009), and social disadvantages (Overby, et al., 2007), although it is unknown if they are co-occurring deficits, or if the lack of speech causes additional deficits. Language deficits were found in 82% (Thoonen, Maassen, Gabreels, Schreuder, & de Swart, 1997) to 100% (Lewis, et al., 2004) of children with CAS. Teachers report lower expectations for children with decreased intelligibility and often view them as having more behavior problems than children with typical speech intelligibility for their age (Overby, et al., 2007).These children need appropriate services at an early age to alleviate difficulties with speech, reduce the co-occurring deficits that occur with significant speech difficulties over an extended time, and ensure they have the same opportunities as other children for achieving academic success.

The American Speech-Language-Hearing Association (ASHA) recently convened a panel to review existing research regarding childhood apraxia of speech (CAS) and, among many conclusions, recommended CAS as a distinct speech sound disorder, indicated a preferred diagnosis of suspected CAS (hereafter referred to as CAS), established identifying characteristics, and determined appropriate treatment techniques. In order for children with CAS to truly demonstrate improvement through learning of speech targets, intensive and individualized therapy and practice are necessary to improve repetitive planning and programming to enhance speech production (ASHA, 2007; Maas, Robin, Hula, Freedman, Wulf, Ballard, et al., 2008). Research revealed improved speech productions in nine to ten year old children given practice (Walsh, Smith, Weber-Fox, 2006). However, there are significant constraints limiting the amount and type of speech therapy a child may receive, including health care reimbursement and caseload size (Maas, et al., 2008). Traditionally, speech-language pathologists provide instruction on challenging speech targets during therapy sessions, with little time devoted to motor speech practice. Home practice allowed children to extend their performance towards mastery through practice beyond scheduled therapy, which led to optimal success (ASHA, 2007; Hudson & Kendall, 2002). Research across multiple disciplines has shown that people who adhered to a home practice routine experienced significantly greater improvements than those who did not practice (Behrman, Rutledge, Hembree, & Sheridan, 2008; Kazantzis, Dattilio & MacEwan, 2005; Kazantzis, Deane & Ronan, 2000; Kazantzis & Lampropoulos, 2002). Therefore, adherence to a practice routine may help children with CAS learn speech skills they initially acquired in the therapy room. Two types of practice, parent-led and computer-led practice, have been identified as potential ways to provide these children with the additional practice they need.

Clinicians frequently rely on parents to practice with their child at home. Although children with a variety of speech disorders have experienced some success with parent-led practice (Bowen & Cupples, 2004; Eiserman, McCoun, & Escobar, 1990; Eiserman, Weber, & McCoun, 1992; Eiserman, Weber, & McCoun, 1995), parents can be extremely busy and struggle to complete home practice with their child due to meeting their basic family obligations as well as maintaining employment outside or inside of the home. Additionally, the established parent-child relationship may change the dynamics of practice when the parent tries to take on a new role of practice partner, practice can become more language-based (Bowen & Cupples, 2004), and cueing trajectories can change (Gardner, 2006), which all can reduce the overall compliance and effectiveness of home practice. Research also revealed limited quantity and integrity of speech practice provided by parents (Pappas, McLeod, McAllister, & McKinnon, 2008). Due to the limitations of parent-led practice, another means of motor speech practice, computer-led practice, has been explored.

Initial success has been reported with computer-supported motor speech practice with children with SSDs (Shriberg, Kwiatkowski, & Snyder, 1989; Shriberg, Kwiatkowski, & Snyder, 1990), children with hearing loss (Clendon, Flynn, & Coombes, 2003), and adults with acquired apraxia of speech (AOS) (Choe, Azuma, Mathy, Liss, & Edgar, 2007), although it has not been studied in children with CAS. Computer-supported speech production tasks led to increased motivation and attention to the task (Nelson &

Masterson, 1999; Shriberg et al., 1989; Shriberg et al., 1990), elicitation of successful practice for those who have already acquired the speech skill (Nelson & Masterson, 1999), and the ability to support therapy through home practice (Clendon et al., 2003). Past studies revealed computer-led practice was equally as effective, efficient, and engaging as clinician-led practice for children with SSDs (Shriberg, et al., 1989; Shriberg, et al., 1990) and in adults it led to greater improvements in speech production when combined with traditional therapy compared to traditional speech therapy alone (Choe et al., 2007). Due to initial evidence supporting computer-led motor speech practice, this technique may hold potential for children with CAS to provide motor speech practice to enhance motor learning.

In order to analyze computer-led practice, the researcher conducted two pilot studies to investigate 1) the impact of parental accountability on various types of motor speech practice patterns and 2) the accuracy of motor speech practice of clinician-led and computer-led practice strategies with children diagnosed with CAS. The first pilot study monitored motor speech practice completion in children with SSDs and CAS during unmonitored practice, computer-led practice, and parent-led practice utilizing a withdrawal design (Nordness & Beukelman, 2010). Eight children, ages 2-7 to 13 years, and their parent(s) were expected to practice their individually selected speech targets 10-minutes a day, seven days a week, in each of the conditions. The researcher created individualized computer programs using Microsoft PowerPoint (2004), which included audio-video clips of the child's SLP modeling the target words. The parent completed a homework record sheet each week of the treatment phases but did not complete a record sheet in the baseline and withdrawal phases.

A review of results revealed only three of eight participants practiced before accountability monitoring, while 100% of the participants increased their overall practice time when recording and reporting parent-led practice with an average increase of 34.3 minutes per week. Six of the eight participants had an additional increase of practice time when recording and reporting computer-led practice, with an additional average increase of 13.5 minutes per week. In the parent-led practice condition, three of the eight participants met the goal of 70 minutes per week and three met half of the goal. In the computer-led condition, three participants met the goal, two met 75% of the goal, one met half of the goal, and two met 25% of the goal. During the withdrawal phase, only one child met the goal and two children met 25% of the goal. During the final computer phase, one participant met the goal, three met 75% of the goal, and the remaining four met half of the goal. Holding families accountable for motor speech practice increased overall practice time. In addition, computer-led practice appeared to offer an additional increase in overall practice time as compared to parent-led practice. At the completion of the study, a social validity survey was conducted with a 62.5% return rate. Parents and children preferred, and were more inclined, to practice in the computer-led condition than in the parent-led condition. Additional comments revealed the computer-led practice helped increase confidence and independence and was more motivating than the parent-led condition (Nordness & Beukelman, 2010).

Due to the greater quantity of practice and the preference for computer-led practice, it was necessary to further study the feasibility of computer-led motor speech practice. Although the first pilot study encouraged accurate practice by selecting targets that were approximately 80% accurate in therapy, accuracy of speech practice was not measured. It is imperative that motor speech practice is accurate to ensure the motor plan is learned correctly (Maas et al., 2008; Schmidt, 1975). Before a computer-led speech practice program is utilized, it is necessary to determine that children can maintain accurate speech productions when practicing with the computer. The standard judgment of whole word accuracy is broad phonetic transcription using the International Phonetic Alphabet (IPA). All speech-language pathologists are trained in phonetic transcription and no additional software or equipment is required for measurement. Unfortunately, reliability of phonetic transcription was reduced when transcribing disordered children's speech (Shriberg & Lof, 1991) and it provided little detailed information. However, phonetic transcription was reported to be a valid measurement tool for research, as long as specific guidelines are consistently followed (Hustad, 2006). Acoustic analysis has been used in conjunction with perceptual analysis as it has been shown to provide more detailed, valuable quantitative data regarding specific sounds, confirm perceptual findings, and track the effects of intervention (Kent, Weismer, Kent, Vorperian, & Duffy, 1999; Mauszycki, Dromey, & Wambaugh, 2007; Shuster & Wambaugh, 2000). Acoustic analysis requires additional training and high-quality software and equipment for recording and analysis. Therefore, acoustic analyses are rarely used in a clinical setting, especially with children. Due to the need for a highly reliable measure of accuracy and clinical practicality, in addition to detailed information about the speech production of children with CAS, utilization of both perceptual judgments of accuracy and acoustic analyses would provide additional information to identify how their speech output varies.

The second pilot study compared the accuracy of speech productions of children with speech sound disorders in clinician-led and computer-led practice conditions. Six children, ages 3-0 to 8-6 years and diagnosed with CAS, participated in the study, which utilized a repeated measures design. Therapy targets were identified by the child's speech-language pathologist, of which the researcher selected 10-15 targets that met the requirements for acoustic analysis. The targets included obstruents, monopthongs (with the exception of low back vowels), and fricatives. To determine if a word was produced accurately, the researcher conducted perceptual judgments using broad phonetic transcription. In addition, productions were analyzed on three acoustic measures: 1) the first and second formants (i.e., F1 and F2) of all monopthongs, 2) spectral base frequency of fricatives, and 3) the voice onset time (VOT) of obstruents. Perceptual scoring revealed children were 85.25% accurate on whole word productions in the clinician-led condition and 86.89% accurate in the computer-led condition. Performance in the computer-led and clinician-led conditions was comparable.

The importance of understanding children's accuracy of speech in various types of motor speech practice is crucial to the feasibility of continued practice outside of the therapy room for children with CAS. In order to further examine children's speech accuracy in various practice options, additional research is needed to compare speech accuracy in parent-led practice to computer-led practice and clinician-led practice. One type of practice that shows potential is computer-led practice due to findings of increased quantity of practice in computer-led practice and parent and children's preference for it. Initial pilot data revealed children's speech accuracy in the computer-led condition was comparable to clinician-led practice. Although these are encouraging results, selection of target words was based on a high standard, between 80-100% accuracy. It is necessary to determine children's accuracy on target words that are not as stable in all three types of practice conditions to determine their ability to support ongoing therapy. Further evidence is needed to determine if this trend is consistent across a larger sample of children with CAS, to compare parent-led, computer-led, and clinician-led practice, and to assess accuracy on words that are less than 80% accurate in therapy.

The purpose of this dissertation is to a) compare the accuracy of speech of children with CAS in three different practice conditions, clinician-led, computer-led, and parent-led practice, measured perceptually, b) compare the mean VOT of obstruents, F1 and F2 frequencies of vowels, and lower frequency limit of spectral frequencies of fricatives in all conditions, and c) compare the variability of F1 and F2 frequencies of vowels, VOT of obstruents, and lower frequency limit of fricatives in all conditions.

Literature Review

Childhood Apraxia of Speech (CAS).

Children diagnosed with a speech sound disorder (SSD) struggle to produce speech sounds, which can lead to significant difficulties with communication. These speech errors may be due to a cognitive, linguistic, or motor impairment or a combination of impairments (Strand & McCauley, 2008). It is vital to understand the level of impairment as treatment techniques differ accordingly. One type of SSD is a motor-based impairment called childhood apraxia of speech (CAS). Although CAS is described as a type of SSD, CAS is reported to more closely resemble the adult acquired apraxia of speech (AOS) rather than children with developmental speech delays (Shriberg et al., 1997a). The primary clinical characteristics of acquired AOS include slow speaking rate, lengthened sounds and durations between sounds, sound distortions, consistent errors, and abnormal prosody (McNeil, Robin, & Schmidt, 1997; Wambaugh, Duffy, McNeil, Robin, & Rogers, 2006). Although not discriminatory of AOS, other characteristics may include articulatory groping, perseverative errors, increased errors with increased word length, difficulty initiating speech, and automatic speech is better than novel speech (McNeil et al., 1997; Wambaugh et al., 2006). A diagnosis of CAS has been difficult to determine in the past due to a lack of behavioral correlates and neural substrates of the disorder (ASHA, 2007). However after years of debate, the American Speech-Language-Hearing Association (ASHA), the national association of speech-language pathologists in the United States, conducted a thorough review of the research and determined that CAS is a definitive diagnosis and is associated with three core features, inconsistent errors in repeated productions, lengthened and disrupted coarticulatory transitions, and inappropriate prosody (ASHA, 2007). These are not necessary and sufficient markers; rather, they are signs that lead one to suspect CAS (ASHA, 2007).

The first core feature of CAS is inconsistent errors on repeated productions of words and/or syllables. In an attempt to confirm a diagnosis of CAS in five children, Davis, Jakielski, and Marquardt (1998) and Marquardt, Jacks, and Davis (2004) reported inconsistent errors across productions as one feature indicative of CAS. They revealed it was a struggle to describe the pattern of errors due to the inconsistency across productions. McCabe, Rosenthal, and McLeod (1998) reported 88% of children with CAS in their study demonstrated inconsistent speech. Maassen, Nijland, and van der Meulen (2001) reported acoustic inconsistency within and in between children with CAS. Inconsistency was also detected across place and manner substitutions (Thoonen, Maassen, Gabreels, & Schreuder, 1994).

The second core feature of CAS is disturbed co-articulation between sounds and syllables. Past research found children with CAS to have more variable and idiosyncratic coarticulatory transitions compared to children with typical speech (Nijland, Maassen, van der Meulen, Gabreëls, Kraaimaat, & Schreuder, 2002). When attempting to sequence syllables on a diadochokinetic task, children with CAS demonstrated significantly more errors on trisyllabic sequence repetition (i.e., /p^t^k^/) than children with spastic dysarthria and children with typical speech (Thoonen, Maassen, Wit, Gabreëls, and Schreuder, 1996). Deficits in coarticulation have also been identified as researchers examined children's ability to program motor speech movements. When a perturbation (i.e., bite block) was imposed on the children with CAS's speech, their coarticulation was impacted and they could not compensate, revealing less distinction between sounds, unlike children with typical speech (Nijland, Maassen, van der Meulen, Gabreëls, Kraaimaat, & Schreuder, 2003). Sussman, Marquardt, and Doyle (2000) also reported evidence that children with CAS have difficulties making maximal distinctions between stop consonants and vowels due to difficulties with coarticulation.

The third core feature of CAS is inappropriate prosody (e.g., rhythm, intonation, and stress). It is frequently reported in the literature as deficient in children with CAS. Davis et al. (1998) identified inappropriate prosody only in CAS as compared to other speech disorders. Although Munson, Bjorum, and Windsor (2003) found children with CAS marked stress acoustically, listeners perceptually could not perceive these distinctions. Shriberg and colleagues have consistently reported deficits in stress as a key feature of CAS (Shriberg, Aram, & Kwiatkowski, 1997b; Shriberg, Aram, & Kwiatkowski, 1997c; Shriberg, Campbell, Karlsson, Brown, McSweeny, & Nadler, 2003; Shriberg, Green, Campbell, McSweeny, & Scheer, 2003). Of all the components of prosody, inappropriate stress was found to distinguish children with CAS from children with a speech delay (Shriberg et al., 1997b), which was consistent in five locations across the United States (Shriberg et al., 1997c). Stress has since been pursued as a possible diagnostic marker for CAS using a lexical stress ratio (Shriberg, Campbell, et al., 2003). A second possible diagnostic marker being considered for CAS, which also reflects prosodic deficits, is the Coefficient of Variation Ratio, a measure of the relationship between variations in pause time and speech time (Shriberg, Green, et al., 2003).

Although research continues to study the level of articulatory breakdown in CAS and AOS, it is generally thought to be a result of deficits in the motor programming or motor planning stage (ASHA, 2007; Ballard, Granier, & Robin, 2000; Darley, Aronson, & Brown, 1975; Hall, Jordan, & Robin, 1993; McNeil, Doyle, & Wambaugh, 2000; McNeil et al., 1997; Nijland, Maassen, & van der Meulen, 2003; Nijland, Maassen, van der Meulen, Gabreels, et al., 2003; van der Merwe, 1997; Wertz, LaPointe, & Rosenbeck, 1984; Yoss & Darley, 1974). A well-established framework of sensorimotor control of speech includes five phases: 1) intent to verbally communicate, 2) linguistic-symbolic planning, 3) motor planning, 4) motor programming, and 5) execution (Van Der Merwe, 1997). In order to verbally communicate, there must be intent to communicate a message. After the intent has been realized, nonmotor processing occurs during the linguistic-symbolic planning phase. At this time, phonological, morphological, semantic, syntactic, and lexical planning occurs to ensure the message follows the rules of the language that is spoken. This information must be translated into a motor code during the motor planning phase. Spatial specifications, such as place and manner of articulation, are determined for the intended phonemes, as well as temporal specifications to sequentially organize the phonemes, which create adaptations reflected in coarticulation. In the following motor programming stage, the fine details such as, muscle tone, joint stiffness, movement direction, force, range, and rate are added into the motor program. During the final execution phase, the motor programs are translated into alpha and gamma motor neurons in the final common pathway to execute the movements (Van der Merwe, 1997). The majority of researchers identified the deficits in CAS and AOS occurring after the intent to communicate has been established but before movement execution occurs, mostly likely the planning and/or programming phases.

Evidence to support motor speech planning/programming breakdowns includes breakdowns at the level of the syllable (Yoss & Darley, 1974), with increasing utterance length (Lewis et al., 2004; Thoonen et al., 1996), with coarticulation (Nijland, Maassen, van der Meulen, 2003), and at the prosodic level (Nijland, Maassen, van der Meulen, et al., 2003). Nijland, Maassen, and van der Meulen (2003) revealed children with CAS evidenced an inability to accommodate to a perturbation in articulation (i.e., bite block) during coarticulatory transitions, compared to children and adult women with typical speech, which reflect deficits in programming speech. Additionally, Marquardt et al. (2004) hypothesized that inconsistency revealed motor planning deficits, since an increase in accuracy coinciding with a decrease in inconsistency appeared to reflect the motor plan becoming more stable.

Since speech is a motor movement and articulatory errors in CAS and AOS are suspected to reflect deficits in planning and sequencing speech motor movements, motor learning is necessary to practice and learn motor plans necessary for speech production (American Speech-Language-Hearing Association, 2005; McNeil et al., 1997; Schmidt & Lee, 2005). Although accurate articulation may be established on demand as a child makes gains in the therapy room, this is considered initial acquisition, not permanent learning (Maas et al., 2008). To promote permanent learning, improvements need to be produced in different environments, positions, contexts, features and linguistic units before a child gains accurate, automatic control of their speech (Bernthal, Bankson, & Flipsen, 2009; Maas et al., 2008). Motor skill learning is facilitated by intensive and individualized practice and factors affecting practice such as stimulus complexity, amount, distribution, variability, schedule, attentional focus, type of feedback, timing of feedback, and feedback frequency (ASHA, 2007; Hula, 2007; Maas et al., 2008). Despite early evidence that identifies a need for variable practice (Adams & Page, 2000; Wambaugh, Kalinyak-Fliszar, West, & Doyle, 1998; Wambaugh, Martinez, McNeil, & Rogers, 1999), with multiple targets (Adams & Page, 2000; Wambaugh, West, & Doyle, 1998), in a random order (Adams & Page, 2000; Knock, Ballard, Robin, & Schmidt, 2000), increased complexity (Maas, Barlow, Robin, & Shapiro, 2002), with a focus on the speech output, and given infrequent, delayed feedback in motor speech learning (Adams & Page, 2000; Adams, Page, & Jog, 2002; Hula, Robin, Maas, Ballard, & Schmidt, 2008; Maas, et al., 2008; Strand, Stoeckel, & Baas, 2006) one factor, the need for practice, underlies all the others. Frequent practice is a fundamental component of motor learning (Caruso & Strand, 1999; Guadagnoli & Lee, 2004; McNeil et al., 1997; Schmidt & Lee, 2005; Strand et al., 2006; Yorkston, Beukelman, Strand, & Bell, 1999) and as one might expect, a greater amount of practice produces greater generalization and eventual retention. Without motor speech practice, conditions of practice cannot be manipulated. It is critical that children with CAS engage in practice to enhance motor speech learning. Two types of motor speech practice, parent-led practice and computer-led practice, have been studied in the past.

Parent-led home practice.

Parent-led practice typically involves a parent providing structured speech practice time at home. The parent provides appropriate speech models for their child, the child repeats all targets, and the parent provides feedback based on their judgment of accuracy. Parent-led practice has led to some reported success (Bowen & Cupples, 2004; Eiserman et al., 1990; Eiserman et al., 1992; Eiserman et al., 1995; Strand et al., 2006).

Bowen and Cupples (2004) developed the Parents and Children Together (PACT) program to provide family centered phonological therapy for young children. One aspect of the PACT model is homework is administered by parents and significant others one to three times a day for five to seven minute intervals. Homework was described as talking, listening, and language games as was reported to occur an average of 15 times per week (range of 8-24 times) per parent report. Most families incorporated practice into story time and utilized a reward system. The authors found that typically 10 of 13 families complied with homework tasks in each cohort. Despite PACT's perceived success, reports are anecdotal and homework was not manipulated separately from the therapy. Therefore, it is impossible to know if the benefits are due to the therapy, the homework, or a combination of the two. The authors also found families individualized homework based on their needs and often incorporated them into language activities (Bowen & Cuppels, 2004). Despite its reported success, further information is needed to determine if parents can implement motor speech learning practice successfully.

Eiserman et al. (1990) conducted a study to compare cost-effectiveness and speech outcomes of speech therapy provided by an SLP to speech therapy provided primarily by a parent in the home, in which there was random assignment of participants to conditions. Parents receive training by an SLP twice a month over a seven-month period in approaches to use with their child. Therapy involved auditory training, speech practice in isolation and words, and language activities. Therapy led by a parent was equally effective as therapy by an SLP, and in a few areas, slightly better, which was corroborated at the end of a second year (Eiserman et al., 1992; Eiserman et al., 1995). However, the authors also found that children and their parent who participated in therapy with their parent did not engage in as much spontaneous conversation after direct therapy training. The disadvantages of home-based parent therapy were parents had little time and often had interruptions, they struggled to work with their own child, and their child had a lack of socialization with other children, while the disadvantages of center-based therapy with an SLP were reported to be greater driving time, need to hire babysitters, no parent-child interaction, and no ongoing training. Additionally, the authors concluded that home-based parent-led therapy was slightly more costly than center-based SLP-led therapy (Eiserman et al., 1990). Despite the success of parent-led therapy, a motor-based learning approach was not included in this study, no distinction was made between therapy and practice, and no attempt was made to study the benefits of parent involvement above and beyond traditional therapy with an SLP.

Researchers will often include parent-led homework in their study, but do not measure its effect. Strand et al. (2006) found parents of four children with severe CAS were willing to engage in five minutes of motor speech practice twice a day. Since it was not a direct part of their study, homework time was not monitored or measured. Although they posited home practice played a role in the success in treatment, there is no way to determine its effect (Strand et al., 2006). Additionally, Ray (2002) asked parents of a five-year-old boy with a phonological disorder in multiple languages to read the target word list twice daily, correct errors on target words as they occur in conversation, and monitor errors in English only. Although parent-led practice was reported to play a role in the child's success, it was not monitored or measures and its effect cannot be determined.

Despite the benefits of parent-led practice, drawbacks have also been reported. Bowen and Cuppels (2004) found families individualized homework based on their needs in ways that led them to become more language-based, such as incorporating them into story time and other language activities. In addition, pilot data by the author revealed children achieve a low level of compliance with motor speech home practice when led by their parent. Gardner (2006) described over the course of a six-month study, parents utilized a different interactional style in speech production practice from the SLP, which occasionally resulted in the children straying away from acceptable productions. Despite 95% of SLPs surveyed in Australia reported requesting parental involvement with speech production practice through home practice, they also reported parental barriers to practice, including limited parental time and capability (Pappas et al., 2008). Although this evidence was often anecdotal, it appears that barriers may exist to parent-led practice, including limited available time, limited quantity, and limited integrity of speech practice provided by parents. Further research is needed to directly monitor and measure the effectiveness of parent-led practice specifically in supporting motor speech practice.

Computer-led practice.

Due to barriers families face providing home motor speech practice, an alternative option is to utilize computer-led home practice opportunities. Computer-led practice involves the speech-language pathologist creating an appropriate structured practice program the child can complete independently on the computer. Although limited research exists on the use of computers in supporting speech production tasks and SLPs reported using computer supported intervention infrequently (Nelson & Masterson, 1999), initial reports revealed computer-supported practice increased motivation and attention to the task (Nelson & Masterson, 1999; Shriberg et al., 1989; Shriberg et al., 1990), elicited successful practice (Nelson & Masterson, 1999; Shriberg et al., 1989; Shriberg et al., 1990), and supported therapy through home practice (Choe et al., 2007; Clendon et al., 2003). Pilot data by the author revealed computer-led home practice individually developed for each child by their SLP increased overall compliance (58%) compared to parent-led practice (21%). Holding families accountable for practice time increase overall time, as all eight participants increased practice time during parent-led practice an average of 34.29 minutes per week, while six of the participants had an additional increase of practice time, mean of 13.12 additional minutes per week, during computer-led practice. These results were further validated by social validity survey results, which indicated parents and children preferred and the computer-led condition.

Shriberg et al. (1989) studied the ability of computer-assisted speech practice to support speech production practice for children with SSDs at the response stabilization phase of speech management, reflected by target productions between 40% and 80% accurate in therapy and no more than 20% generalization in spontaneous speech. The authors compared tabletop speech management to computer-assisted speech management in terms of effectiveness (i.e., accuracy of productions), efficiency (i.e., time spent on task), and engagement (i.e., verbal and nonverbal interaction behaviors between the child and the clinician) across two studies, which counterbalanced order of presentation and time to follow-up (i.e., one-week and two-weeks respectively). At the time of the study in the mid-1990s, computer technology was not as well developed as current technology. They presented their stimuli on a 128K Apple IIe microcomputer with a 65C02 microprocessor. Although occasional differences were identified, when analyzed across both studies, tabletop and computer versions were found to be equally effective, efficient, and engaging. Although greater time needed for the computer activity, greater eye contact with the clinician during tabletop activity, and greater inattentiveness during the tabletop activity were occasionally noted, those findings were not replicated across both studies. In addition, both children and clinicians preferred the computer activity to the tabletop activity. Anecdotal comments identifying the benefits of the computer activity revealed greater interest and responsivity of the child and clinician and the clinician had more control over the activity. Drawbacks of the computer activity were children appeared distracted by the mechanics and had difficulty learning placements between the trackpad input device and the screen. The results of this study revealed that computer assisted therapy is feasible. Some of the drawbacks of the computer activity were likely due to the dated technology (Shriberg et al., 1989). Current technology supporting high quality graphics and sound would likely resolve those drawbacks. Despite the well-controlled study between the two conditions and appropriate targets, practice was done in collaboration with a clinician. It is unknown if a child could complete the computer practice independently during practice rather than therapy, if they could produce targets at the response stabilization level without the need for feedback from a clinician, and if children with CAS would be successful with this technique.

To further assess the appropriateness of target selection, Shriberg et al. (1990) expanded the previous study by utilizing targets at the response evocation phase (i.e., between 20% and 40% accurate) and adding a fantasy-based activity, which included an interactive digitized robot, as an attempt to encourage engagement. Results were consistent with the previous study. All three conditions, tabletop activity, computer activity, and fantasy-based activity, were equally effective, efficient, and engaging. Although many children preferred the computer + robot fantasy activity, they did not perform better on any of the measures in this condition. The authors suspected the robot's speech was difficult to understand due to the basic technology at that time. In the response evocation phase, children continued to receive feedback on their accuracy of target productions and they received credit for just being close to the appropriate targets (Shriberg et al., 1990). At this phase, children needed large amounts of clinician instruction to be successful; therefore, this phase is not appropriate for independent practice (Shriberg, et al., 1990). Since motor learning practice needs to maintain a high level of accuracy, targets at a response stabilization phase are more appropriate for motor speech practice.

Clendon et al. (2003) found that five children with cochlear implants improved their speech production after eight months of computer-based training. Although the study also focused on language skills, the children used SpeechViewer III, a software program that provides audiovisual feedback during activities targeting pitch, prosody, voicing, and phonology, to specifically target articulation. Articulation activities targeted phoneme accuracy and sequencing and they were completed with a clinician present to help select appropriate difficulty level, provide feedback, and record an accurate model of production. A significant improvement was found in speech accuracy from pre- to mid- and post-intervention based on percentage of consonants correct (PCC) score measured by broad phonetic transcription from single-word picture naming stimuli. Although significant gains were found in speech production accuracy, a clinician was present during all training and no control group was utilized. Therefore, the role of the computer above and beyond working with a clinician is still unknown.

Choe et al. (2007) researched the effect of computer-based practice above and beyond therapy with a clinician in four adults with acquired anomia and apraxia of speech due to a cerebrovascular accident (CVA). The participants participated in a naming task in three conditions, computer practice, weekly practice with an SLP, and a control condition, measured with the Porch Index of Communicative Ability (PICA) scale. The participants engaged in each condition simultaneously, for 16 weeks, using three different target sets of words. A maintenance check was completed five weeks after the end of treatment. Participants utilized a home computer to run a PowerPoint program with their practice targets. Practice logs indicated practice time ranged from 20-39 minutes per day for the computer condition. Two of four participants made significant improvements in the computer condition, with three reaching significant at the maintenance check. Only one participant reached significance in the weekly practice with a clinician and no participants reached significance at the maintenance check. In the control condition, no participants reached significance at the end of the treatment or at the maintenance check. Interestingly, the three participants who made significant improvements at the maintenance check in the computer condition chose to let the computer program run automatically, while the one who did not reach significance manually controlled the computer program via mouse clicks and reported the lowest amount of computer practice each day. A review of the results of this study revealed independent computer practice to lead to greater gains than weekly practice with a clinician and a no practice condition. Despite the benefits, progress was measured from a naming perspective for the anomia diagnosis and not based on accuracy of speech production. In addition, once a week speech therapy may not be representative of the amount of therapy individuals with apraxia typically receive. Further research is needed to compare speech accuracy across the various conditions and to determine the effects are also seen in children with CAS.

Although there is limited research on computer programs to support speech sound production in children, initial results reveal it is equally or more effective than parent-led practice and clinician-led practice and leads to greater compliance. Motor speech targets need to be chosen carefully, to ensure children have adequately acquired them in the therapy room before progressing to independent practice at home. Initial research suggests a response stabilization phase, between 40% and 80% accurate in therapy and no more than 20% accurate in spontaneous speech, is appropriate for motor speech practice (Shriberg et al., 1989; Shriberg et al., 1990). To ensure children maintain appropriate productions at the response stabilization level during independent practice, it is imperative to monitor the accuracy of their productions.

Accurate productions.

Children with CAS appear to need appropriate and consistent practice to enhance overall speech production accuracy. It is also imperative that motor speech practice is accurate to ensure the motor plan is learned correctly (Maas et al., 2008; Schmidt, 1975). Speech sound accuracy is typically measured through broad or narrow phonetic transcription using the International Phonetic Alphabet (IPA) in a clinical setting. Although phonetic transcription is the most common technique, reliability measures of transcription decrease when transcribing children's speech, disordered speech, and using diacritic markers (Shriberg & Lof, 1991). However, perceptual assessment of speech accuracy continues to be used in research, typically measured by a percent of correct productions (Choe, et al., 2007; Clendon, et al., 2003; Jacks, Marquardt, & Davis, 2006; Katz, Carter, & Levitt, 2007; Knock, et al., 2000; Raymer, Haley, & Kendall, 2002; Shriberg, et al., 1989; Shriberg, et al., 1990; Wambaugh, 2004; Wambaugh et al., 1998; Wambaugh, Martinez et al., 1999; Wambaugh & Nessler, 2004). Phonetic transcription was found to be a valid measurement tool for research, as long as specific guidelines are followed (Hustad, 2006). Phonetic transcription is required due to its heavy use in clinical procedures, although it tells us little about the phonetic details of children with CAS's speech.

Acoustic analysis.

A more robust method of assessment of speech accuracy includes acoustic analysis, as it provides valuable sources of quantitative data, can track the effects of intervention, and it is necessary to identify subtle phonetic differences, such as tongue displacement, voice onset time, vowel durations, and intensity variations (Kent et al., 1999; Nijland et al., 2002). Acoustics of normal and disordered adult speech has been extensively studied, while children's speech lacks much normative data. Therefore, a review of acoustic data from children and adults is warranted. Acoustic analysis of speech typically involves measuring perceived intelligibility through consonant and vowel analyses, and measuring prosody through intonation, rate, rhythm, voice, and intensity analyses (Kent & Kim, 2003; Shriberg & Kent, 2003).

Acoustic analysis of consonants.

Common acoustic measures of consonants for individuals with speech sound disorders include voice onset time (VOT) for stops and spectral pattern, formant transitions, and spectral tilt for fricatives. The majority of the analyses were conducted using KayPENTAX's Computerized Speech Lab or Boersma & Weenink's Praat.

Voice onset time reflects the interval between the release of a plosive burst and the onset of the following vocal fold vibration and represents articulator-laryngeal coordination. Young children demonstrate a shorter lag time between the burst and vocal fold vibration, which lengthens as they age (Baken & Orlikoff, 2000). Preadolescent children and older adults are also reported to have more variable VOT (Auzou, Ozsancak, Morris, Jan, Eustache, & Hannequin, 2000). Lengthened and more variable VOT was reported in adults with apraxia of speech (Auzou, et al., 2000; Ball, Code, Tree, Dawe, & Kay, 2004; Ballard et al., 2000) and in adults with dysarthria (Auzou, et al., 2000; Kent & Kim, 2003). Although speaking rate, age, and context can alter VOT, comparison data are available for adults with typical speech and adults with apraxia of speech and dysarthria (Auzou, et al., 2000; Baken & Orlikoff, 2000). Even though normative data is not available for children, VOT continues to be an acceptable acoustic measure due to its frequency of use, ease of analysis, and its ability to use as a comparison for an individual in multiple conditions.

Fricatives, especially /s/, have been the focus of much research due to their frequency of use in our language, a well-defined spectral pattern (Kent & Kim, 2003), and a high frequency of errors due to its high precision requirement (Chen & Stevens, 2001). A typical /s/ has a spectral peak around 3,500 to 7,000 Hz for adults (Chen & Stevens, 2001) and 8,300-8,400 Hz for children (Baken & Orlikoff, 2000). Changes in the peak energy can reveal clues to articulator placement, as the closer the fricative to the front of the oral cavity, the higher the energy frequency (Baken & Orlikoff, 2000; Shuster & Wambaugh, 2000). Variation of the spectrum shape of /s/ was correlated the highest with intelligibility and perceptual ratings (Chen & Stevens, 2001). Additionally, the lower frequency limit of /s/ and "sh" were found to be 3,600 Hz and 2,200 Hz respectively (Nittrouer, 1992; Nittrouer, 2002; Nittrouer & Studdert-Kennedy, 1987). Due to its strong relationship to intelligibility, normative data in children, and high frequency of errors in children, the spectral pattern of fricatives, especially /s/ and "sh," is a valuable acoustic measure for children with speech sound disorders.

Since consonants are extremely dependent on the following vowel, second formant (F2) transitions, which represent coarticulation between a consonant and a vowel, are frequently studied. The duration between the /s/ and the following vowel is under 50 ms in adults and was found to be the second highest correlation to perceptual ratings and intelligibility (Chen & Stevens, 2001). F2 transitions in general were found to have normal variability for adults with apraxia of speech (Ballard, et al., 2000). Another way coarticulation was measured in typically developing infants and toddlers through formant transition was by computing a locus equation. The locus equation is a linear regression between the F2 frequency onset and at the middle of the following vowel, sampled with one consonant and a range of vowels. When analyzing results, the greater the slope, the greater the coarticulation (Sussman, Duder, Dalston, & Cacciatore, 1999). Liss and Weismer (1992) studied the qualitative differences of the F2 transition and found the typical F2 trajectories were steeper than those adults with apraxia.

Coarticulation is frequently disrupted in children with speech sound disorders; however, acoustic measures of coarticulation are not well developed for children at this time.

A more recent measure of the tongue blade position during production of /s/ is spectral tilt. Spectral tilt compares the high frequency energy relative to the amplitude of mid-frequency energy, with a normal score of 5-20 dB in adults (Chen & Stevens, 2001). Speakers with dysarthria were found to have lower than anticipated spectral tilt, often times below zero, indicating poor tongue blade position (Chen & Stevens, 2001). This technique may hold potential for acoustic analysis in the future, but has not been well utilized at this time.

Acoustic analysis of vowels.

Determining the accuracy of vowels acoustically is most accurate when comparing the relative formant frequency peaks of different vowels to each other within the same speaker, since formant patterns reflect the size and shape of the vocal tract, which differs from person to person and across ages (Baken & Orlikoff, 2000). Despite this difficulty, formant frequency data for all vowels is available for men, women, boys and girls (Baken & Orlikoff, 2000).

Raised vowel formants were found for an adult with apraxia of speech compared to typical speakers (Ball, et al., 2004). Mixed results were found in children who wear cochlear implants between their implant on and off conditions (Poissant, Peters, & Robb, 2006) and in adults with apraxia of speech (Haley, Ohde, & Wertz, 2001). When assessing the overall mobility of the tongue on all vowel productions, vowel space was found to be restricted in adults with dysarthria (Kent & Kim, 2003). In order to compare across children with apraxia, researchers utilized an /i/:/u/ ratio to represent the distinction between vowels, rather than specific frequencies (Nijland, Maassen, & van der Meulen, 2003). Vowel formants remain a useful acoustic measure to compare an individual in multiple conditions.

Acoustic analysis of prosody.

Stress, the emphasis perceived in speech, is impacted by frequency, intensity and duration characteristics. Children with speech sound disorders may have deficits in making distinctions in their speech using stress. One of the core characteristics of children with CAS is a deficit in prosody, especially lexical and phrasal stress (ASHA, 2007). Shriberg, Campbell, et al. (2003) proposed a measure of stress as a diagnostic marker for children with CAS called the lexical stress ratio (LSR). The LSR is computed using the amplitude area, fundamental frequency area, and duration, which were selected based on a factor analysis (Shriberg, Campbell, et al., 2003). Although the LSR of children with CAS was significantly different than children with other speech delays, some children used excessive stress, others used reduced stress, and still others appeared to have no stress deficits (Shriberg, Campbell, et al., 2003). However, no significant differences were found between children with CAS and children with phonological disorders on acoustic measures of duration, fundamental frequency, and intensity in a subsequent study (Munson et al., 2003). In addition, a recent study by Patel and Brayton (2009) found a stabilization in measures of prosody, specifically mean fundamental frequency, mean intensity, and duration, between the ages of four and seven. Acoustic measures of stress are revealing variable results. Unfortunately, since its reliability is not well established and variability may be appropriate in children, its usefulness in establishing the effectiveness of treatment approaches is not recommended at this time.

In some speech sound disorders, such as apraxia, the temporal characteristics of speech are affected. This is often measured by the duration of sounds, words, and sentences. Strand and McNeil (1996) found longer vowel durations in all conditions (i.e., words, word strings, and sentences) in adults with acquired apraxia of speech compared to a control group, with the greatest difference at sentence level, indicating increased difficulty with increased complexity. Reductions in durations of fricatives and glides were reported for adults with apraxia of speech after treatment, although it appeared overall reduction in sentence durations were not due to the treatment (Wambaugh et al., 1998). Additionally, no significant reductions in word or initial-syllable durations were found after treatment in an adult with apraxia (Wambaugh & Martinez, 2000). However, word durations were found to be significantly greater in children with CAS compared to children with phonological disorders and typical articulation (Bahr, 2005). Durations of various sound segments appear to give mixed results at this time.

Disruption of temporal characteristics can also affect the pauses between speech events. Strand and McNeil (1996) found increased between-word segment durations in adults with apraxia compared to controls. Increased duration and variability of inter-stress intervals in sentences was found in adults with spinoerebellar ataxia (Schalling & Hartelius, 2004). The coefficient of variation ratio (CVR) has been established to compare pause events and speech events in a single speaker by dividing the coefficient of variation (COV) of speech events by the COV of pause events as a possible diagnostic marker for children with apraxia of speech. A low CVR indicates less variability in pause events, while a high CVR indicates less variability in speech events (Shriberg, Green, et al., 2003). Although there was little distinction between children with CAS, speech disorders, and normal speech acquisition when isolating the COV for speech events and COV for pause events, when analyzing the data as a function of speech and pause events together using the CVR, children with CAS were significantly higher than all others (Shriberg, Green, et al., 2003). Due to the consistent results of increased inter-segment durations for children and adults with speech disorders and the ability to analyze a longer unit of speech, inter-segment measures would likely provide valuable information in assessing improvements in longer utterances.

To assess speech sound production at the word level in children with CAS, it appears the most reliable acoustical measures to compare treatment conditions are voice onset time of plosives, spectral patterns of fricatives (especially /s/), vowel formants (F1 and F2), and comparisons of pause and speech time (Auzou et al., 2000; Bahr, 2005; Baken & Orlikoff, 2000; Ball et al., 2004; Ballard et al., 2000; Chen & Stevens, 2001; Kent & Kim, 2003; Nijland, Maassen, & van der Meulen, 2003; Nittrouer, 1992; Nittrouer, 2002; Nittrouer & Studdert-Kennedy, 1987; Shuster & Wambaugh, 2000; Wambaugh & Martinez, 2000; Wambaugh, et al., 1998). Although determining accuracy based on multiple acoustic measures in whole word utterances is rarely done in the literature, these acoustic measures have been used in isolation or to measure variability over repeated utterances of the same target word.

Research on variability of speech production in adults with AOS have revealed mixed results over the years and far less research conducted with children. Although Shriberg et al. (1997b) reported highly variable errors did not distinguish children with CAS from children with other speech sound disorders and children's speech movements are inherently more variable than adults, researchers continued to study variability to identify descriptive information about the speech production of children with CAS. Sussman et al. (2000) found increased variability in consonant placement, as evident from the F2 value of the vowel following the consonant, in five children with CAS compared to children with typical speech production. Researchers also identified increased variability in F2 trajectories of VCCV and VCV utterances in children with CAS compared to children with typical speech production and adult women with typical speech (Maassen et al., 2001; Nijland et al., 2002).

Skinder, Strand, and Mignerey (1999) found greater intersubject variability in children with CAS compared to a control group when measuring stress perceptually and acoustically as the participants attempted to match the prosodic contour of short sentences. Although small group differences were found, the authors identified discrepancies between acoustical and perceptual scoring and found even greater variability when analyzing individual variability within the children with CAS. The authors speculated that segmental errors may have interfered with judges' interpretation of stress when measured perceptually (Skinder et al., 1999).

Although a small sample size limits the applicability of the results, Marquardt et al. (2004) found highly variable productions of sounds and sequences of sounds over a period of three years in three children with CAS. They also reported a general trend of decreased variability with increased accuracy over time. Overall, currently available information on variability in children with CAS identifies the need for perceptual and acoustical measurements in addition to group and individual analysis of data.

In developing a way to help children with CAS make greater gains in their sound system, we must focus on two critical elements: (1) Type of practice and (2) accurate productions. The purpose of this dissertation is to a) compare the accuracy of speech of children with CAS in three different practice conditions, clinician-led, computer-led, and parent-led practice, measured perceptually, b) compare the mean VOT of obstruents, F1 and F2 frequencies of vowels, and lower frequency limit of spectral frequencies of fricatives in all conditions, and c) compare the variability of F1 and F2 frequencies of vowels, VOT of obstruents, and lower frequency limit of fricatives in all conditions.

Hypotheses

1. Do children with SSDs with CAS achieve comparable accuracy of speech measured perceptually when completing independent practice led by a clinician, a computer and their parent?

   It was hypothesized that perceptual accuracy in the computer-led condition would result in speech accuracy that is comparable to the clinician-led condition and the parent-led condition, which would make it a viable home practice program for children with CAS.
2. Do children with CAS achieve comparable vowel F1 and F2 productions when completing independent practice led by a clinician, a computer and their parent?

   It was hypothesized that the vowel F1 and F2 productions in the computer-led condition would be comparable to the clinician-led and the parent-led condition.
3. Do children with CAS achieve comparable base spectral frequencies of fricative productions when completing independent practice led by a clinician, a computer and their parent?

It was hypothesized that the spectral base frequencies of fricative productions in the computer-led condition would be comparable to the clinician-led condition and the parent-led condition.

4. Do children with CAS achieve comparable voice onset times/final durations of stop productions when completing independent practice led by a clinician, a computer and their parent?

   It was hypothesized that the voice onset times/final durations of stop productions in the computer-led condition would be comparable to the clinician-led condition and the parent-led condition.

5. Do children with CAS achieve comparable variability across F1 and F2 of vowel productions, spectral base frequencies of fricatives, and voice onset times/final durations of stop productions when completing independent practice led by a clinician, a computer and their parent?

   It was hypothesized that the variability across all three acoustical measurements in the computer-led condition is comparable to the clinician-led condition and the parent-led condition, which will make it a viable home practice program for children with CAS.

CHAPTER 2: PERCEPTUAL COMPARISONS OF MOTOR SPEECH PRACTICE OPTIONS FOR CHILDREN WITH CHILDHOOD APRAXIA OF SPEECH

Introduction

Children diagnosed with a childhood apraxia of speech (CAS) struggle to communicate basic needs, exhibit unintelligible speech, struggle to develop sounds, strain to blend sounds together to form words, and cannot control the inflection of their voice, despite no muscular deficits (ASHA, 2007). Difficulties sequencing sounds appear to be due to a motor planning and/or programming deficit. Exact prevalence is unknown, however differing reports state 1-2 of every 1,000 children (Shriberg et al., 1997a) and 3.4-4.3% of speech-impaired preschoolers (Delany & Kent, 2004) have CAS. CAS is often accompanied by language and literacy deficits (ASHA, 2007; Lewis, et al., 2004; Lewis et al., 2006; Mirenda & Mathy-Laikko, 1989; Thoonen et al., 1997), academic difficulties (Lewis et al., 2000; Overby et al., 2007; Teverovsky et al., 2009) deficits in phonological processing and literacy (Lewis, et al., 2000; Lewis et al.2004; McNeill et al., 2009), and social disadvantages (Overby, et al., 2007). These children desperately need appropriate services at an early age to alleviate difficulties with speech, reduce the co-occurring deficits that occur with significant speech difficulties over an extended time, and ensure they have the same opportunities as other children for achieving academic success.

In order for children with CAS to truly demonstrate improvement through learning of speech targets, intensive and individualized therapy and practice are necessary to improve repetitive planning and programming to enhance speech production (ASHA, 2007; Maas et al., 2008). However, there are significant constraints limiting the amount and type of speech therapy a child may receive, including health care reimbursement and caseload size (Maas, et al., 2008). Traditionally, speech-language pathologists provide instruction on challenging speech targets during therapy sessions, with little time devoted to motor speech practice. Given more frequent practice time and greater repetitions, children with CAS have to shown to make greater progress than children with CAS who receive less frequent practice time and fewer repetitions (Edeal & Gildersleeve-Neumann, in press). Home practice allowed children to extend their performance towards mastery through practice beyond scheduled therapy, which led to optimal success (ASHA, 2007; Hudson & Kendall, 2002). Research across multiple disciplines has shown that people who adhered to a home practice routine experienced significantly greater improvements (Behrman et al., 2008; Kazantzis et al., 2005; Kazantzis et al., 2000; Kazantzis & Lampropoulos, 2002; Nordness & Beukelman, 2010). Therefore, adherence to a practice routine may help children with CAS facilitate the learning of speech skills they initially acquired in the therapy room.

Two types of practice, parent-led and computer-led practice, have been identified as potential ways to provide these children with the additional practice. Clinicians frequently rely on parents to provide this additional practice with their child. Although children with a variety of speech disorders have experienced some success with parent-led practice (Bowen, 2004; Eiserman et al., 1990; Eiserman et al., 1992; Eiserman et al., 1995), parents can be extremely busy and struggle to complete home practice with their child due to family obligations and employment outside or inside of the home. Additionally, the established parent-child relationship may change the dynamics of practice when the parent tries to take on a new role of practice partner. Practice can become more language-based (Bowen, 2004) and cueing trajectories can change (Gardner, 2006), which all can reduce the overall compliance and effectiveness of home practice. Research also revealed limited quantity and integrity of speech practice provided by parents (Pappas et al., 2008). Due to the limitations of parent-led practice, another means of motor speech practice, computer-led practice, has been explored.

Initial success has been reported with computer-supported motor speech practice with children with SSDs (Shriberg et al., 1989; Shriberg et al., 1990), children with hearing loss (Clendon et al., 2003), and adults with acquired apraxia of speech (AOS) (Choe et al., 2007), although it has rarely been studied in children with CAS. Computer-supported speech production tasks led to increased motivation and attention to the task (Nelson & Masterson, 1999; Shriberg et al., 1989; Shriberg et al., 1990), elicitation of successful practice for those who have already acquired the speech skill (Nelson & Masterson, 1999), and the ability to support therapy through home practice (Clendon et al., 2003; Nordness & Beukelman, 2010). Past studies revealed computer-led practice was equally as effective, efficient, and engaging as clinician-led practice for children with SSDs (Shriberg, et al., 1989; Shriberg, et al., 1990) and in adults it led to greater improvements in speech production when combined with traditional therapy compared to traditional speech therapy alone (Choe et al., 2007). Nordness and Beukelman (2010) examined motor speech practice completion in eight children with CAS, aged 2-7 to 13 years, during unmonitored practice, parent-led practice, and computer-led practice, which utilized individualized computer programs using Microsoft PowerPoint (2004). Only three of eight participants practiced before accountability monitoring, while 100% of the participants increased their overall practice time when recording and reporting parent-led practice with an average increase of 34.3 minutes per week. Six of the eight participants had an additional increase of practice time when recording and reporting computer-led practice, with an additional average increase of 13.5 minutes per week. Holding families accountable for motor speech practice increased overall practice time. In addition, computer-led practice appeared to offer an additional increase in overall practice time as compared to parent-led practice. Results revealed parents and children preferred, and were more inclined, to practice in the computer-led condition. Due to initial evidence supporting computer-led motor speech practice, this technique may hold potential for children with CAS to provide motor speech practice to enhance motor learning.

Due to the greater quantity of practice and the preference for computer-led practice, it is necessary to further study the feasibility of computer-led motor speech practice. It is imperative that motor speech practice is accurate to ensure the motor plan is learned correctly (Maas et al., 2008; Schmidt, 1975). Before a computer-led speech practice program is utilized, it is necessary to determine that children can maintain accurate speech productions when practicing with the computer. The standard judgment of whole word accuracy is broad phonetic transcription using the International Phonetic Alphabet (IPA). Phonetic transcription was reported to be a valid measurement tool for research, as long as specific guidelines are consistently followed (Hustad, 2006). Pilot data by the researcher revealed children were 85.25% accurate on whole word productions in the clinician-led condition and 86.89% accurate in the computer-led condition measured with broad phonetic transcription. Performance in the computer-led and clinician-led conditions was comparable.

The importance of understanding children's accuracy of speech in various types of motor speech practice is crucial to the feasibility of continued practice outside of the therapy room for children with CAS. In order to further examine children's speech accuracy in various practice options, additional research is needed to compare speech accuracy in parent-led practice to computer-led practice and clinician-led practice. One type of practice that shows potential is computer-led practice due to findings of increased quantity of practice in computer-led practice and parent and children's preference for it. Initial pilot data revealed children's speech accuracy in the computer-led condition was comparable to clinician-led practice. Although this is encouraging data, selection of target words was based on a high standard, between 80-100% accuracy. It is necessary to determine children's accuracy on target words that are not as stable in all three types of practice conditions. Further evidence is needed to determine if this trend of better results with computer-led practice is consistent across a larger sample of children with CAS, in order to compare parent-led, computer-led, and clinician-led practice and to assess accuracy on words that are less than 80% accurate in therapy.

The purpose of this study is to compare the accuracy of speech of children with CAS in three different independent practice conditions, clinician-led, computer-led, and parent-led practice, measured perceptually. It was hypothesized that the computer-led condition will result in speech accuracy that is comparable to the clinician-led condition and the parent-led condition, which will make it a viable home practice strategy for children with CAS.

Methods

Participants

Twelve children (N = 12) diagnosed with a SSD that appeared to be CAS, between 3-0 and 7-11 years of age, participated in the study. Collaborating SLPs working in Scottish Rite RiteCare Clinics in urban Midwestern cities recruited participants by identifying children with CAS, sharing basic information about the project, and providing a phone number and e-mail address to contact the researcher through the researcher's pilot study (Nordness & Beukelman, 2010) and ongoing clinical work.

The criteria for participation included: 1) Diagnosis of a SSD with CAS, 2) primary native language of the child and parent(s) is Standard American English, 3) normal hearing as determined by a standard hearing screening (ASHA, 1997), 4) within one standard deviation of the mean on a measure of receptive vocabulary, and 5) no known cognitive deficits per parent report. The procedures to determine necessary criteria are discussed in a subsequent section. Participants were excluded from the study if they had other diagnosed neuromotor conditions and if they were unable to comply/cooperate with any of the tasks.

In accordance with the ASHA (2007) guidelines for diagnosing children with CAS, the children in this study were expected to display the following three speech characteristics indicative of CAS based on a majority decision of a panel of three SLPs: (1) Inconsistent errors across repeated productions, (2) disturbed co-articulation between sounds and syllables, and (3) inappropriate prosody. Speech characteristics were obtained from an informal 12-minute speech sample, from which the middle 10-minutes was analyzed. This was obtained through informal discussion about a topic (e.g., "Tell me about your favorite game/movie," "Tell me how you make cookies/pizza," etc.).

Additionally, the researcher prompted the child to repeat occasional words that were pronounced incorrectly.

Participants completed a series of tests to assess their hearing, verbal production, and auditory comprehension at the beginning of the study. Participants completed a hearing screen at 1, 2, and 4 kHz in a quiet environment using a portable audiometer. Participants completed the Verbal Motor Production Assessment for Children (VMPAC) (Hayden & Square, 1999) to describe overall speech motor performance of the participant population. In addition, participants were administered the Peabody Picture Vocabulary Test – 4 (PPVT) (Dunn & Dunn, 2006) and the Test of Auditory Comprehension of Language – Third Edition (TACL-3) (Carrow-Woolfolk, 1999) to assess the participants' receptive knowledge of spoken grammar, vocabulary, and syntax (Table 2.1).

Table 2.1. Characteristics of participants with childhood apraxia of speech.

Participant	Sex	Age	Diagnosis	Hearing Screen	TACL-3	PPVT-4	VMPAC - GMC	VMPAC - FOC	VMPAC - S	VMPAC - CSLC	VMPAC - SC
1	M	5-8	sCAS; ADHD	pass	74	89	95.00%	68.66%	41.30%	35.56%	28.57%
2	M	5-1	sCAS	pass	91	86	100.00%	72.01%	39.13%	57.78%	42.86%
3	F	3-8	sCAS	pass	104	98	100.00%	62.31%	36.96%	68.89%	85.71%
4	M	4-9	sCAS	pass	102	99	95.00%	72.39%	67.39%	64.44%	71.43%
5	F	6-1	sCAS; SLI	pass	94	95	100.00%	90.30%	67.39%	82.22%	57.14%
6	M	5-11	sCAS	pass	74	85	85.00%	63.81%	32.61%	42.22%	57.14%
7	F	7-10	sCAS; ADHD	pass	79	89	100.00%	92.91%	73.91%	88.89%	71.43%
8	F	5-7	sCAS	pass	96	92	95.00%	72.01%	36.96%	60.00%	42.86%
9	F	5-8	sCAS	pass	100	107	100.00%	69.78%	52.17%	68.89%	42.86%
10	M	3-0	sCAS	pass	100	98	80.00%	45.15%	4.35%	40.00%	57.14%
11	M	6-7	sCAS	pass	74	94	100.00%	75.75%	47.83%	77.78%	57.14%
12	M	5-5	sCAS	pass	91	112	100.00%	80.60%	54.35%	75.56%	57.14%

Procedures

Consent was obtained from the parents of potential participants prior to testing. Additionally, the child aged 7-0 provided assent to participate by signing with their parent on the parental consent form. Each child attended five sessions in a quiet setting. Children participated in formal and informal testing (i.e., VMPAC, PPVT-4, TACL-3, speech sample, hearing screen, informal interview with parent) during Session One to certify them as a participant. This session was approximately 1.5 - 2 hours long, with two to three breaks provided to keep the child's attention.

Once a child was verified as meeting participant criteria, the researcher obtained a list of potential target words from the child's speech-language pathologist (SLP). Session Two identified 5-7 target words that fell in the response stabilization phase (i.e., between 40% and 80% accurate in therapy) (Shriberg, et al., 1989) and met acoustical target criteria for the second part of the study (See Chapter 3) prior to data collection. The children produced their target words after the researcher provided a verbal model. No additional cues or feedback were given. The researcher perceptually determined accuracy using broad phonetic transcription using the International Phonetic Alphabet (IPA). This session was approximately 30-minutes long.

Data collection was conducted during Sessions Three through Five. The order of the conditions was counterbalanced to prevent order effects and each condition was separated by 2-3 days, as is reported in similar studies (Adams & Page, 2000; Shriberg et al., 1989), to reduce the potential for learning across conditions. Each child's SLP was asked to refrain from treatment on the target sounds during the course of the study. Each data collection session was approximately 10-15 minutes in length. All participants took part in three conditions: computer-led practice, clinician-led practice, and parent-led practice. Each data collection session involved 10 repetitions of each target word for a total of 50-70 productions per session.

(1) **Computer-led Practice**: The selected target words were embedded into a program developed with Microsoft® PowerPoint 2004. One word was targeted per slide and each displayed a digital photograph or color line drawing of the target and the written word on the screen. The researcher recorded audio files with the internal computer microphone using the *"Record Narration"* function in PowerPoint, with approximately four seconds for each slide. A cube right transition was applied to each slide to indicate the next target was approaching. The slides were then randomized. Ten cartoon animations were integrated randomly into the program to provide occasional reinforcement. The animations were developed using PowerPoint "*Custom Animation"* and "*Sound Effects"* in the slide show options. The program ran automatically on a Macintosh 13" MacBook after it was manually started.

(2) **Clinician-led Practice:** The researcher led all clinician-led practice conditions to ensure consistency across subjects. The researcher provided a verbal model of each target word while displaying a corresponding flashcard, which displayed the same digital photograph or color line drawing of the target and the written word as in the computer-led practice. After each spoken model by the researcher, the child produced the word. During these data collection sessions, the researcher did not provide feedback related to accuracy of the productions. However, the researcher gave occasional words of encouragement (i.e., keep it up, good try, you're working hard) through participation in the project. The same 10 cartoons displayed on

flashcards were integrated randomly into the program to provide occasional reinforcement.

(3) **Parent-led Practice**: Parents provided a verbal model of each target word while displaying a corresponding flashcard, which again displayed the previously used digital photograph or color line drawing of the target and the written word, provided by their child's SLP. After each model, the child produced the word. The parent was instructed to not provide feedback, but was allowed to give occasional previously identified words of encouragement throughout the protocol. The same 10 cartoons displayed on flashcards were integrated randomly into the program to provide occasional reinforcement.

Materials

Selection of Target Words. The target words were determined based on the children's individual needs, a common procedure in the literature, to assess words that were representative of appropriate practice targets (Ballard, Maas, & Robin, 2007; Choe, et al., 2007; Davis, Jacks, & Marquardt, 2005; Hula et al., 2008; Knock et al., 2000; Shriberg, et al., 1989; Shriberg, et al., 1990; Strand et al., 2006; Wambaugh, 2004; Wambaugh et al., 1998). The researcher selected 5-7 words for each participant, depending on each child's situation and compliance, out of all the possible target words. All selected words fell in the response stabilization phase (i.e., between 40% and 80% accurate) (Shriberg, et al., 1989) and met phonetic criteria for acoustical analysis. In each condition, the child completed a 50-70-item speech task, consisting of the 5-7 targets each repeated ten times. To prevent order effects, the order of words in each condition was randomized. Target words were identified, screened, and selected one to two weeks prior to data collection.

Equipment

Each session was digitally audio recorded in Audacity® on a 2.16 GHz Intel Core 2 Duo MacBook, using a Crown CM-312A head mounted unidirectional Condenser Microphone, placed three inches from the corner of the child's mouth for optimal recording and pre-amplified using a Behringer Xenyx 502 mixer. The analog voice signal was digitized at a sampling rate was 22,050 Hz with a 16-bit quantization. Data was backed-up in two locations, (1) a secure, 360GB iomega external hard drive, model #MDHD360-UE, which was in a different location from the computer, and (2) a password-protected network server.

Preparation of the Speech Samples for analysis. Prior to analysis, each individual word was separated from the entire audio file using Audacity® on a 2.16 GHz Intel Core 2 Duo MacBook into a separate file for ease of analysis.

Measures

Perceptual scoring and reliability. Perceptual scoring, the standard clinical procedure for determining whole word accuracy, was utilized to measure accuracy of all productions. All perceptual scoring was based on broad IPA phonetic transcription. The researcher, a certified speech-language pathologist trained in phonetic transcription, phonetically transcribed all target words via the digital audio samples. A second certified speech-language pathologist trained in phonetic transcription conducted a reliability check. The researcher reviewed the scoring form and practiced phonetic transcription of words and phrases with the SLP using the Shriberg and Kent (2003) practice modules.

Training was complete when the reliability checker reached 90% consistency in the phonetic transcription. The 2nd SLP phonetically transcribed 30% of the total target words across all participants as a reliability check. Inter-rater reliability on consonants was 82.92% and on vowels was 89.07%, which has been shown to be consistent with past practice for interjudge reliability (Shriberg & Lof, 1991).

Analyses

The analysis utilized a k-group repeated measures design with Tukey's Honestly Significant Difference Minimum Mean Difference (HSDmmd) follow-up pairwise comparisons to compare the perceptual accuracy of target productions in the three conditions of independent practice (i.e., Clinician, Computer and Parent) to determine their feasibility for independent practice. The independent variable was the type of practice and the dependent variables were percent consonants correct (PCC) and percent vowels correct (PVC).

Results

The descriptive data are presented in Table 2.2. A review of results revealed no significance in percentage of consonants correct across conditions, F (2, 22) = 1.725, p= 0.201, Mse = 12.394. No significance was observed in percentage of vowels correct across conditions, F (2, 22) = 0.587, p= 0.564, Mse = 26.632.

Table 2.2. Mean percentage of consonants correct and percentage of vowels correct across the three conditions.

	Condition		
Dependent Variable	Computer	Parent	SLP
Percentage of Consonants Correct	80.75%	78.40%	80.66%
Percentage of Vowels Correct	87.23%	84.98%	85.77%

Results of consonants correct across individual participants are shown in Figure 2.1. The average difference between the highest and lowest PCC across conditions and participants was 5.46 percentage points (range 0.71-13.70). Results of vowels correct across individual participants are shown in Figure 2.2. The average difference between the highest and lowest PVC across conditions and participants was 7.62 percentage points (range 2.14-21.43). Additionally, results separated by phoneme are shown in Figure 2.3. The average difference between the highest and lowest percentage across conditions across all phonemes was 7.27 percentage points (range 0.00-40.00), with the greatest difference on the phonemes /u/ (40.00), /o/ (17.50), /g/ (10.00), /v/ (10.00), and /k/ (9.78).

Figure 2.1. Percentage of consonants correct across participants and conditions.

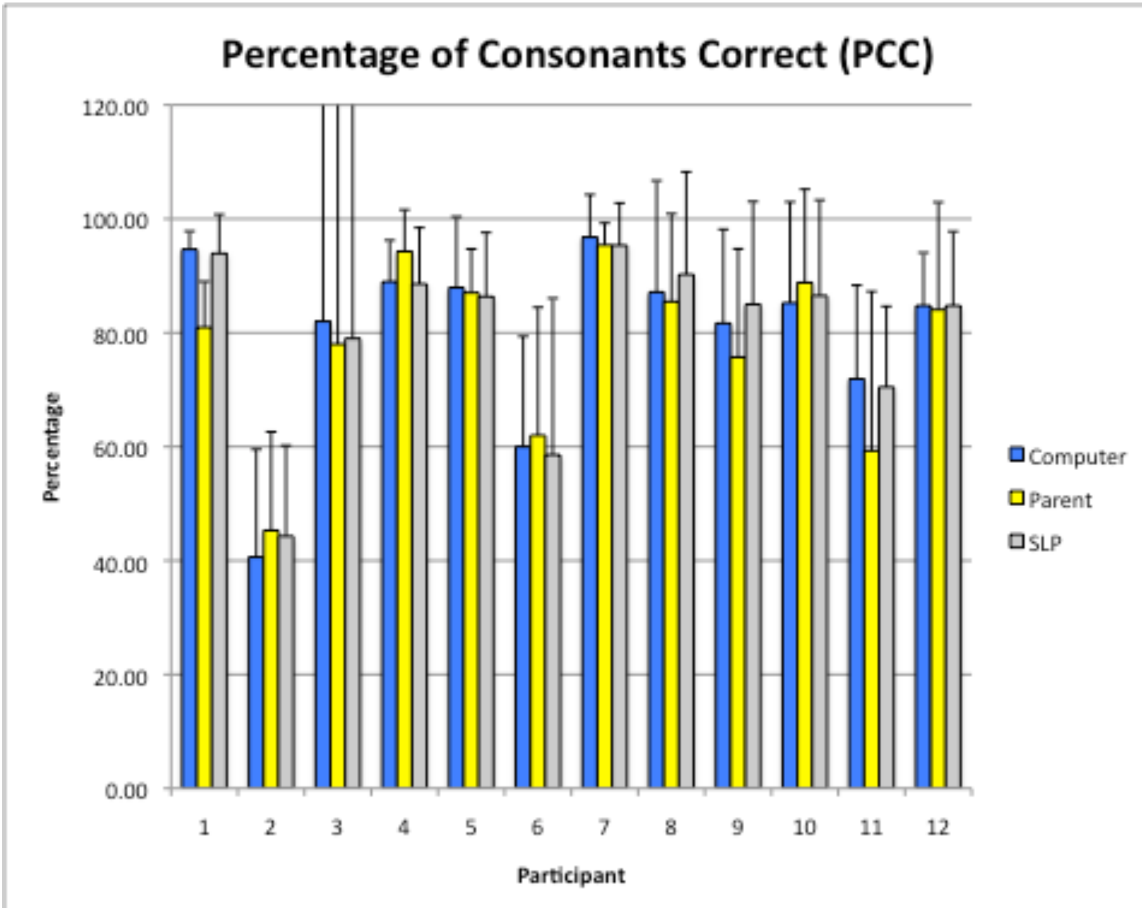


Figure 2.2. Percentage of vowels correct across participants and conditions.

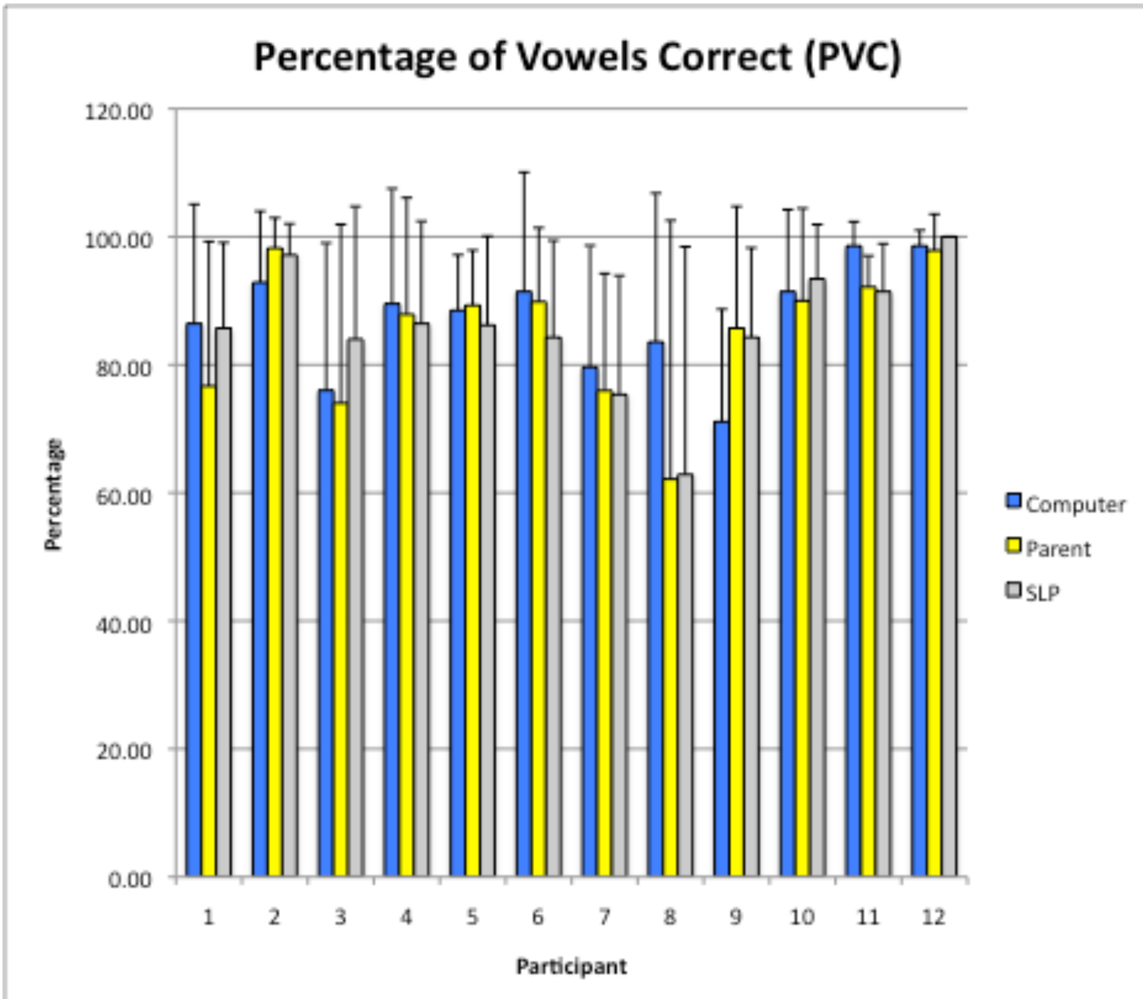
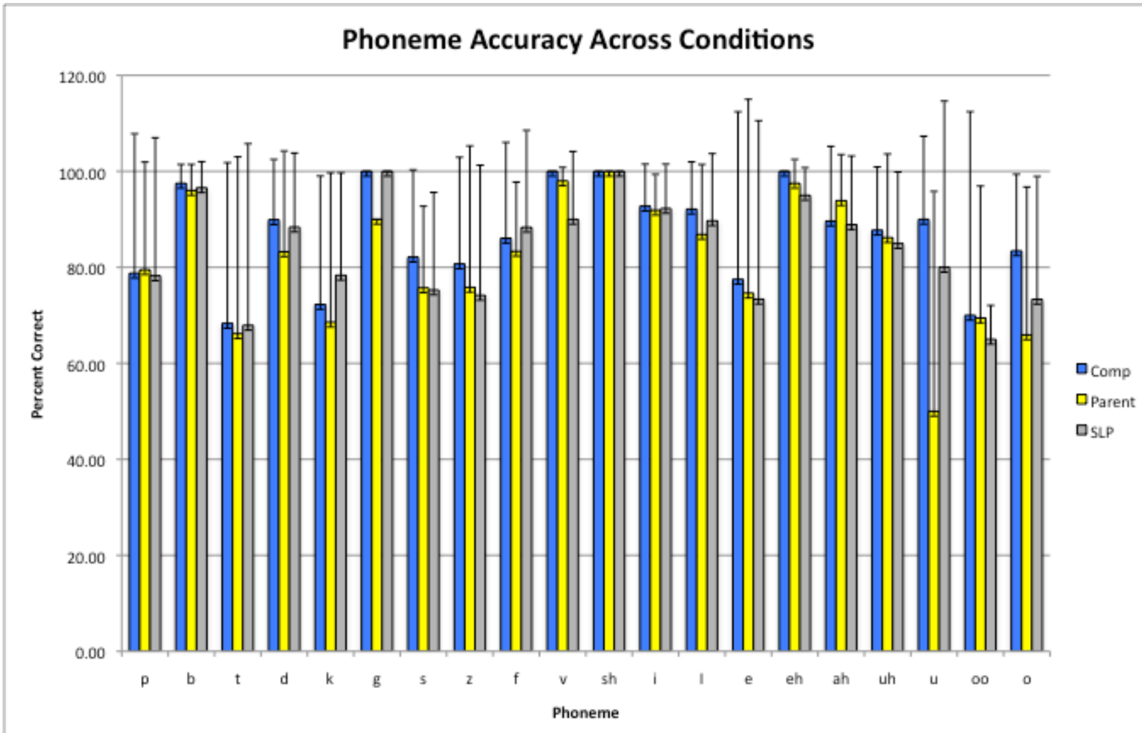


Figure 2.3. Accuracy of individual phonemes across all conditions.



Two major error types were scored across conditions: (1) out of class substitutions (i.e., errors that were out of the manner of production class, such as stops for fricatives) and (2) deletions (i.e., deletion of a phoneme) (See Table 2.3). The greatest number of out of class substitutions occurred in the clinician-led condition (73), followed by the parent-led condition (63), and then the computer-led condition (60). The greatest number of deletions occurred in the parent-led condition (70), followed by the clinician-led condition (66), and then the computer-led condition (56).

Table 2.3. Types of errors across all three conditions.

	Condition		
Error Type	Computer	Parent	Clinician
Out of class substitutions	60	63	73
Deletions	56	70	66

Discussion

We hypothesized that there would be no significant results across conditions. This hypothesis was supported by the results, which revealed that overall there were no significant differences between perceptual accuracy of consonants and vowels during the three practice conditions. This indicates that the computer-led practice leads to speech productions that are as accurate as current practice (i.e., parent- or clinician-led practice). Despite no significant differences, when results are individually viewed across participants, a review of results revealed slightly more difficulty maintaining accuracy on vowels compared to consonants.

When the data are compared across individual phonemes across the three conditions, the phonemes with the greatest variability in accuracy across conditions were /u, o, g, v, k/, primarily all back sounds. On the phonemes /g, v, u, o/, the highest accuracy was in the computer-led condition, while the /k/ had the highest accuracy in the clinician-led condition. The phonemes /k, g, u, o/ had their lowest accuracy in the parent-led condition, while the /v/ was lowest in the clinician-led condition. Overall, phonemes made in the back of the mouth were less accurate in the parent-led condition than in the computer-led and clinician-led conditions. Productions of back sounds may be produced more accurately when given a model produced by the SLP, whether face-to-face or recorded in computer-led practice, and should be monitored carefully when working with parent(s).

Errors also seem to be impacted by the practice partner. Participants made the fewest out of class substitution and deletion errors in the computer-led condition. It is possible that the recorded model provided a consistent model across all repetitions, which lead to fewer errors.

Overall, individually developed computer-led practice appears to be a viable option for accurate practice for children with CAS. Past results have also revealed that children are motivated by computer-led practice and it leads to increased quantity of practice. Increased motivation and increased quantity of practice combined with maintaining accurate speech productions leads to a combination of factors that appear to provide the support for effective, computer-led speech production practice for children with CAS. Due to their need for intense, individualized therapy and practice, computer-led speech practice may provide the extra support they need to improve their speech production.

Limitations

One limitation of this study is that the target words were different for each participant, which made it more difficult to compare accuracy across conditions as compared to a homogenous group. However, the target words were of the same accuracy level (40-80% accurate) to each individual participant. Using a consistent target set across participants would have likely led to targets that were too easy for some and too challenging for others, likely resulting in ceiling and floor effects. Choosing words that reflect a consistent accuracy level place all participants on a similar “playing field.” In addition, practice on words that are between 40-80% accuracy more accurately reflects the practice needs for children with CAS, which in turn can have a direct impact on their treatment.

A second limitation of the study was accuracy was only measured perceptually, which lacks more specific information on children's speech productions. Therefore, in part two of this dissertation, acoustic results are also measured.

Conclusion

In this study the researcher attempted to determine if computer-led speech practice was a viable independent practice strategy for children with CAS by comparing the perceptual accuracy of speech in computer-led practice to two other modes of delivery in current practice, clinician-led and parent-led practice. A review of results revealed computer-led practice led to speech production that was equally accurate compared to speech production in clinician-led and parent-led conditions. Additionally, computer-led practice led to fewer out-of-class substitution and deletion errors and led to more accurate productions on back phonemes. Consistent with previous results, computer-led speech practice led to a greater quantity of practice and was preferred to other practice options (Nordness & Beukelman, 2010), accurate speech production during computer-led speech practice establishes computer-led speech practice as an appropriate practice tool for children with CAS.

CHAPTER 3: ACOUSTICAL COMPARISONS OF MOTOR SPEECH PRACTICE OPTIONS FOR CHILDREN WITH CHILDHOOD APRAXIA OF SPEECH

Introduction

Children diagnosed with a childhood apraxia of speech (CAS) have difficulties planning/programming a sequence of sounds to produce speech despite no muscular deficits. These children often exhibit severely unintelligible speech, a limited sound repertoire, difficulty sequencing sounds, and impaired prosody (ASHA, 2007). They frequently experience co-occurring deficits affecting language, literacy, academics, and phonological processing (ASHA, 2007; Lewis et al., 2004; Lewis et al., 2000; McNeill et al., 2009; Teverovsky et al., 2009).

Intensive and individualized therapy and practice are recommended to enhance speech production and long-term improvements (ASHA, 2007; Maas et al., 2008). Unfortunately, limited health care reimbursement and large caseload sizes restrict the amount and type of speech therapy a child may receive (Maas et al., 2008). Given more frequent practice time, children with CAS have to shown to make greater progress (Edeal & Gildersleeve-Neumann, in press). In order to devote therapy time to instruction, speech-language pathologists often rely on home practice led by a parent to give the child the necessary repetition for motor learning to occur. Adherence to a home practice routine led to significantly greater improvements across many disciplines (Behrman et al., 2008; Kazantzis et al., 2005; Kazantzis et al., 2000; Kazantzis & Lampropoulos, 2002; Nordness & Beukelman, 2010). Children with CAS may also benefit from a home practice routine to refine and perfect the speech skills they initially acquired in the therapy room.

Parent-led practice has been shown to be successful at times (Bowen, 2004; Eiserman et al., 1990; Eiserman et al., 1992; Eiserman et al., 1995), although evidence has also shown the dynamics of practice change when the parent tries to be a practice partner, practice can become more language-based, and cueing trajectories can change (Bowen, 2004; Gardner, 2006). Additionally, research also revealed the amount of practice was reduced and the integrity of speech practice was impacted when provided by parents (Pappas et al., 2008).

A review of research on an alternate practice option, computer-supported motor speech practice, revealed effectiveness with children with a variety of speech deficits (Clendon et al., 2003; Shriberg et al., 1989; Shriberg et al., 1990), as well as adults with acquired apraxia of speech (AOS) (Choe et al., 2007). Computer-supported speech production tasks led to increased motivation and attention (Nelson & Masterson, 1999; Shriberg et al., 1989; Shriberg et al., 1990), elicitation of successful practice (Nelson & Masterson, 1999), greater quantity of practice (Nordness & Beukelman, 2010), served as a supplement to therapy (Choe et al., 2007; Clendon et al., 2003; Nordness & Beukelman, 2010), and was preferred over parent-led practice (Nordness & Beukelman, 2010). Computer-led practice revealed potential to support motor speech practice in children with CAS.

In order to establish an accurate motor plan, speech productions must be accurate to ensure it is learned correctly (Maas et al., 2008; Schmidt, 1975). Researchers conducted the previous study (see Chapter 2) to determine if children with CAS maintain speech accuracy when completing computer-led practice. Participants completed speech practice in three conditions, computer-led, parent-led, and clinician-led practice. Researchers analyzed all productions using broad phonetic transcription according to the International Phonetic Alphabet (IPA). Results revealed no significant differences between perceptual accuracy of consonants and vowels during the three practice conditions; therefore, computer-led practice led to speech productions that were as accurate as current practice. A closer look at the evidence reveled slightly more difficulties with back sounds, although the highest accuracy of back sounds was in the computer-led condition. Additionally, the fewest number of out of class substitution and deletion errors occurred in the computer-led condition. Past results of computer-led practice revealed increased motivation and increased quantity of practice, combined with maintaining accurate speech productions provides the support for computer-led practice as a viable mode of practice for children with CAS. However, a more detailed analysis is needed to understand the differences between speech productions in the three practice conditions and further analyze the differences in sounds.

Acoustic analysis provides more detailed, valuable quantitative data regarding specific sounds and is often used to confirm perceptual findings (Kent et al., 1999; Mauszycki et al., 2007; Shuster & Wambaugh, 2000). The most reliable acoustical measures of speech sounds when comparing treatment conditions are voice onset time of plosives, lower spectral frequency limit of fricatives (especially /s/), and vowel formants (F1 and F2) (Auzou et al., 2000; Baken & Orlikoff, 2000; Ball et al., 2004; Ballard et al., 2000; Chen & Stevens, 2001; Kent & Kim, 2003; Nijland et al., 2003; Shuster & Wambaugh, 2000). Voice onset time reflects the interval between the release of a plosive burst and the onset of the following vocal fold vibration and represents articulator-laryngeal coordination. Despite no normative data for VOT in children, it is frequently analyzed due to its frequency of use, ease of analysis, and its ability to be used as a comparison across multiple conditions. A review of the literature has shown lengthened and more variable VOT in adults with AOS (Auzou, et al., 2000; Ball et al., 2004; Ballard et al., 2000), variable VOT in typically developing preadolescents (Auzou et al., 2000), and lengthened VOT as children age (Baken & Orlikoff, 2000).

Fricatives, especially /s/, are often analyzed due to their high frequency of use in Standard American English, a well-defined spectral pattern (Kent & Kim, 2003), and a high frequency of errors due to its high precision requirement (Chen & Stevens, 2001). Variation of the spectrum shape of /s/ was correlated the highest with intelligibility and perceptual ratings (Chen & Stevens, 2001). A typical /s/ has a spectral peak around 8,300-8,400 Hz for children (Baken & Orlikoff, 2000), although the lower spectral frequency can be made with a more precise measurement (Heinz & Stevens, 1961; Raphael, 2008). Although frequencies of fricatives can vary due to coarticulation, measurement of the lower spectral frequency was sufficient to measure identical words across conditions, as the contexts would be identical across conditions. Due to its strong relationship to intelligibility, availability of normative data in children, and high frequency of errors in children, the spectral pattern of fricatives is a valuable acoustic measure for children with speech sound disorders.

Since normative data is available for vowel formants and the formant patterns reflect the size and shape of an individual's unique vocal tract, they are an accurate and useful acoustic measure to compare an individual across multiple conditions (Baken &

Orlikoff, 2000). Past research on vowel formant for speech sound errors revealed raised vowel formants in adults with AOS compared to typical speakers (Ball et al., 2004), restricted vowel space in adults with dysarthria (Kent & Kim, 2003), and mixed results in children who wear cochlear implants between their implant on and off conditions (Poissant et al., 2006) and in adults with AOS (Haley et al., 2001).

Inconsistency of speech productions has also been reported as a key characteristic in children with CAS (ASHA, 2007). Researchers continued to study variability to identify descriptive information about the speech production of children with CAS. Children with CAS displayed increased variability in consonant placement compared to children with typical speech production (Sussman et al., 2000) and increase variability of F2 trajectories of VCCV and VCV utterances compared to children and adult women with typical speech production (Maassen et al., 2001; Nijland et al., 2002). In order to analyze variability across different sounds/measures, the data must be normalized using the coefficient of variation. Due to the importance of maintaining accurate productions during motor learning, it is vital to assess variability of productions as well.

To assess speech sound accuracy in detail at the word level in children with CAS, it appears the most reliable acoustical measures to compare treatment conditions are voice onset time of plosives, lower spectral patterns of fricatives, and vowel formants (F1 and F2), in addition to measuring variability with the coefficient of variation. Although determining accuracy based on multiple acoustic measures in whole word utterances is rarely done in the literature, these acoustic measures have been used in isolation or to measure variability over repeated utterances of the same target word. Further evidence is needed to compare precise speech accuracy across parent-led, computer-led, and clinician-led practice to determine the potential for computer-led practice.

The purpose of this study was to compare the accuracy of speech of children with CAS in three different independent practice conditions, clinician-led, computer-led, and parent-led practice, measured acoustically using a) the mean VOT/Final duration of stops, b) mean F1 and F2 frequencies of vowels, c) the mean lower spectral frequency limit of fricatives, and d) the mean variability across all three acoustic measures. It was hypothesized that the computer-led condition will result in speech accuracy and variability that is comparable across all three acoustical measurements to the clinician-led condition and the parent-led condition.

Methods

Participants

Twelve children (N = 12) diagnosed with CAS, between 3-0 and 7-11 years of age, participated in the study. Collaborating SLPs working in Scottish Rite RiteCare Clinics in urban midwestern cities recruited participants by identifying children with CAS through the researcher's pilot study (Nordness & Beukelman, 2010) and ongoing clinical work.

The criteria for participation included: 1) diagnosis of a SSD with CAS, 2) primary native language of the child and parent(s) was Standard American English, 3) normal hearing as determined by a standard hearing screening (ASHA, 1997), 4) within one standard deviation of the mean on a measure of receptive vocabulary, and 5) no known cognitive deficits per parent report. Participants were excluded from the study if they had other diagnosed neuromotor conditions and if they were unable to comply/cooperate with any of the tasks. The children were expected to display the following three speech characteristics indicative of CAS based on a majority decision of a panel of three SLPs: (1) Inconsistent errors across repeated productions, (2) disturbed co-articulation between sounds and syllables, and (3) inappropriate prosody (ASHA, 2007). Speech characteristics were obtained from an informal 12-minute speech sample, from which the middle 10-minutes was analyzed. This was obtained through informal discussion about a topic (e.g., “Tell me about your favorite game/movie,” “Tell me how you make cookies/pizza,” etc.). Additionally, the researcher prompted the child to repeat words that were occasionally pronounced incorrectly.

Participants completed a series of tests to assess their hearing, verbal production, and auditory comprehension at the beginning of the study. Participants completed a hearing screen at 1, 2, and 4 kHz in a quiet environment using a portable audiometer. Participants completed the Verbal Motor Production Assessment for Children (VMPAC) (Hayden & Square, 1999) to describe overall speech motor performance of the participant population. In addition, participants completed the Peabody Picture Vocabulary Test – 4 (PPVT) (Dunn & Dunn, 2007) and the Test of Auditory Comprehension of Language – Third Edition (TACL-3) (Carrow-Woolfolk, 1999) to identify the participants’ receptive knowledge of spoken grammar, vocabulary, and syntax (Table 2.1).

Procedures

Consent was obtained from the parents of potential participants prior to testing. Additionally, the child aged 7-0 provided assent to participate by signing with their parent on the parental consent form. Each child attended five sessions in a quiet setting. Children participated in formal and informal testing (i.e., VMPAC, PPVT-4, TACL-3, speech sample, hearing screen, informal interview with parent) during Session One to certify them as a participant. This session was approximately 1.5 - 2 hours long, with two to three breaks provided to keep the child's attention.

Once a child was certified as meeting the selection criteria for a participant, the researcher obtained a list of potential target words from the child's speech-language pathologist (SLP). Session Two certified 5-7 target words that fell in the response stabilization phase (i.e., between 40% and 80% accurate in therapy) (Shriberg, et al., 1989) and met acoustical target criteria, including monopthongs (with the exception of low back vowels), fricatives, and stops, and excluded diphthongs and blends. The children produced their target words after the researcher provided a verbal model. No additional cues or feedback were given. The researcher perceptually determined accuracy using broad phonetic transcription using the International Phonetic Alphabet (IPA). This session was approximately 30-minutes long.

Data collection was conducted during Sessions Three through Five. The order of the conditions was counterbalanced to prevent order effects and each condition was separated by 2-3 days, as is reported in similar studies (Adams & Page, 2000; Shriberg et al., 1989), to prevent learning across conditions. Each child's SLP was asked to refrain from treatment on the target sounds during the course of the study. Each data collection session was approximately 10-15 minutes in length. All participants took part in three conditions: computer-led practice, clinician-led practice, and parent-led practice.

1. **Computer-led Practice**: The selected target words were embedded into a program developed with Microsoft® PowerPoint 2004. One word was targeted per slide and each displayed a digital photograph or color line drawing of the

target and the written word on the screen. The researcher recorded audio files with the internal computer microphone using the *"Record Narration"* function in PowerPoint, with approximately four seconds for each slide. A cube right transition was applied to each slide to indicate the next target was approaching. The slides were then randomized. Ten cartoon animations were integrated randomly into the program to provide occasional reinforcement. The animations were developed using PowerPoint "*Custom Animation"* and "*Sound Effects"* in the slide show options. The program ran automatically on a Macintosh 13" MacBook after it was manually started.

2. **Clinician-led Practice:** The researcher led all clinician-led practice conditions to ensure consistency of practice across subjects. The researcher provided a verbal model of each target word while displaying a corresponding flashcard, which displayed the same digital photograph or color line drawing of the target and the written word as in the computer-led practice. After each spoken model by the researcher, the child produced the word. During these data collection sessions, the researcher did not provide feedback accuracy. However, the researcher was allowed to give occasional words of encouragement (i.e., keep it up, good try, you're working hard) through participation in the project. The same 10 cartoons displayed on flashcards were integrated randomly into the program to provide occasional reinforcement.
3. **Parent-led Practice**: Parents provided a verbal model of each target word while displaying a corresponding flashcard, which again displayed the previously used digital photograph or color line drawing of the target and the written word,

provided by their child's SLP. After each model, the child produced the word. The parent was instructed to not provide feedback, but was allowed to give occasional previously identified words of encouragement throughout the protocol. The same 10 cartoons displayed on flashcards were integrated randomly into the program to provide occasional reinforcement.

Materials

Selection of Target Words. The target words were determined based on the children's individual needs, a common procedure in the literature, to assess words that were representative of appropriate practice targets (Ballard et al., 2007; Choe et al., 2007; Davis et al., 2005; Hula et al., 2008; Knock et al., 2000; Shriberg et al., 1989; Shriberg et al., 1990; Strand et al., 2006; Wambaugh, 2004; Wambaugh et al., 1998). The researcher selected 5-7 words for each participant, depending on each child's situation and compliance, out of all the possible target words. All selected words fell in the response stabilization phase (i.e., between 40% and 80% accurate) (Shriberg et al., 1989) and met phonetic criteria for acoustical analysis. In each condition, the child completed a 50-70-item speech task, consisting of the 5-7 targets each repeated ten times. To prevent order effects, the order of words in each condition was randomized. Target words were identified, screened, and selected one to two weeks prior to data collection.

Equipment

Each session was digitally audio recorded using Audacity® on a 2.16 GHz Intel Core 2 Duo MacBook, with a Crown CM-312A head mounted unidirectional Condenser Microphone, placed three inches from the corner of the child's mouth for optimal recording and pre-amplified using a Behringer Xenyx 502 mixer. The analog voice signal was digitized at a sampling rate was 22,050 kHz with a 16-bit quantization. Data was backed-up, according to IRB requirements for confidentiality, in two locations, (1) a secure, 360GB iomega external hard drive, model #MDHD360-UE, which was in a different location from the computer, and (2) a password-protected network server.

Preparation of the Speech Samples for analysis. Prior to analysis, each individual word was separated from the entire audio file using Audacity® on a 2.16 GHz Intel Core 2 Duo MacBook into a separate file for ease of analysis.

Measures

The principal investigator conducted acoustic analyses using WaveSurfer (Sjolander & Beskow, 2006) to assess children's productions for three measures, the first and second formants frequencies (i.e., F1 and F2) of all monopthongs, lower spectral frequency limit of fricatives, and the voice onset time (VOT) and final duration of stops, in each condition. For the analysis, the Fast Fourier transform (FFT) window was set at 512 points, utilizing a Blackman window, and a window bandwidth of 64 points. F1 and F2 measurements were taken at the centroid of the formant. The centroid was computed by identifying the duration between the beginning and the end of F1 and then dividing by two. VOT was described as the interval between the onset of the energy burst and the first vocal fold vibration of the following vowel. The final stop duration was computed for stops in the final position of words, by measuring the point from the onset of stop closure to the burst of the stop release. The lower spectral frequency limit of fricatives was identified by the lowest change in high contrast of the formants.

Analyses

The analysis utilized a k-group repeated measures design with Tukey's Honestly Significant Difference Minimum Mean Difference (HSDmmd) follow-up pairwise comparisons to compare the acoustical measures of 1) F1 and F2 spectral frequencies of all monopthongs, 2) VOT of all obstruents, and 3) the lowest spectral frequency limit of all fricatives across all target productions in the three conditions of independent practice (i.e., Clinician, Computer and Parent). The independent variable was the type of practice and the dependent variables were the first and second formants frequencies (i.e., F1 and F2) of all monopthongs, lower spectral frequency limit of fricatives, and the voice onset time (VOT)/final duration of stops. Eight of the ten repetitions of each word for each participant were analyzed to allow for eliminating samples with recording interference.

Due to occasional phoneme deletions and out of class substitutions, the total N for each phoneme occasionally varied. In order to compute an ANOVA, the sample size was equalized using the most common data imputation analysis, the maximum likelihood estimation. A mean of 3.28 data points were imputed per analysis (4.81%).

Additionally, the overall variability was then computed using the Coefficient of Variation (COV) ((standard deviation/mean)*100) for the three separate acoustic measures. Specifically, a COV was computed for the F1 and the F2 of all monopthongs, spectral base frequency of all fricatives, and the voice onset time (VOT) of all stops across all participants. In order to understand variability in more detail, variability scores were also analyzed across individual phonemes.

Results

F1 and F2 Formant Frequencies of Monopthongs.

Tables 3.1 and 3.2 summarize the data for average F1 and F2 for all vowels across all three conditions. The values of the overall F-test, p-values, MSe, and pairwise follow-ups tests are reported in Table 3.3. Results of F1 across all vowels are shown in Figure 3.1 and results of F2 across all vowels are shown in Figure 3.2.

Table 3.1. Means and standard deviations of F1 for each vowel across all three conditions.

	Condition		
F1	Computer	Parent	SLP
/ i /	499.89 (109.26)	499.59 (118.67)	496.26 (106.66)
/ I /	679.00 (136.98)	664.45 (142.40)	662.19 (148.84)
/ e /	657.52 (166.23)	635.19 (139.00)	666.34 (150.89)
/ ε /	783.32 (139.99)	776.49 (155.09)	760.59 (173.37)
/ æ /	1173.92 (161.54)	1162.30 (175.76)	1144.74 (203.13)
/ ə /	840.55 (191.98)	816.38 (200.16)	816.02 (228.27)
/ u /	568.81 (151.17)	604.56 (114.82)	594.37 (141.37)
/ ʊ /	687.51 (149.90)	697.67 (156.23)	677.90 (141.55)
/ o /	634.57 (163.51)	642.07 (164.63)	625.92 (146.32)

Table 3.2. Means and standard deviations of F2 for each vowel across all three conditions.

	Condition		
F2	Computer	Parent	SLP
/ i /	3182.33 (371.64)	3215.23 (378.81)	3266.49 (363.65)
/ I /	2696.85 (337.77)	2664.16 (332.03)	2613.87 (343.08)
/ e /	2931.24 (367.86)	2995.12 (354.43)	2946.54 (361.89)
/ ε /	2498.60 (287.72)	2529.47 (296.49)	2510.58 (321.56)
/ æ /	2367.05 (185.62)	2391.41 (211.22)	2382.94 (176.36)
/ ə /	2103.51 (410.57)	2083.98 (367.35)	2103.90 (383.33)
/ u /	1767.13 (472.69)	1817.07 (502.50)	1764.39 (449.80)
/ ʊ /	1633.13 (230.04)	1648.13 (251.11)	1664.47 (312.44)
/ o /	1513.71 (343.39)	1614.27 (362.89)	1537.60 (287.08)

Table 3.3. Overall F-test, P value, mean square error, HSD minimum mean difference value, and significant pairwise follow-up tests for F1 and F2 of all vowels.

Vowel (Formant)	*F*	P	MSe	HSDmmd	Significant follow-up tests
/ i / (F1)	0.108 (2,444)	.898	8420.211		
/ I / (F1)	0.999 (2,340)	.369	14247.040		
/ e / (F1)	2.966 (2,302)	.053	13211.642		
/ ɛ / (F1)	0.305 (2,78)	.738	17850.063		
/ æ / (F1)	1.130 (2,222)	.325	21394.578		
/ ə / (F1)	2.137 (2,414)	.119	19243.532		
/ u / (F1)	0.699 (2,46)	.502	11646.629		
/ ʊ / (F1)	0.068 (2,30)	.934	22832.953		
/ o / (F1)	0.567 (2,206)	.568	11984.634		
/ i / (F2)	4.215 (2,444)	.015*	95175.197	68.381	Computer vs. Clinician
/ I / (F2)	7.221 (2,340)	.001*	41376.302	51.487	Computer vs. Clinician
/ e / (F2)	3.234 (2,302)	.041*	52280.216	61.386	Computer vs. Parent
/ ɛ / (F2)	0.265 (2,78)	.768	36520.617		
/ æ / (F2)	0.931 (2,222)	.396	18399.288		
/ ə / (F2)	0.464 (2,414)	.629	58198.263		
/ u / (F2)	0.694 (2,46)	.505	30410.516		
/ ʊ / (F2)	0.057 (2,30)	.945	68844.418		
/ o / (F2)	4.700 (2,206)	.01*	61078.839	81.426	Computer vs. Parent

* Significant

Figure 3.1. F1 values of individual vowels across all conditions.

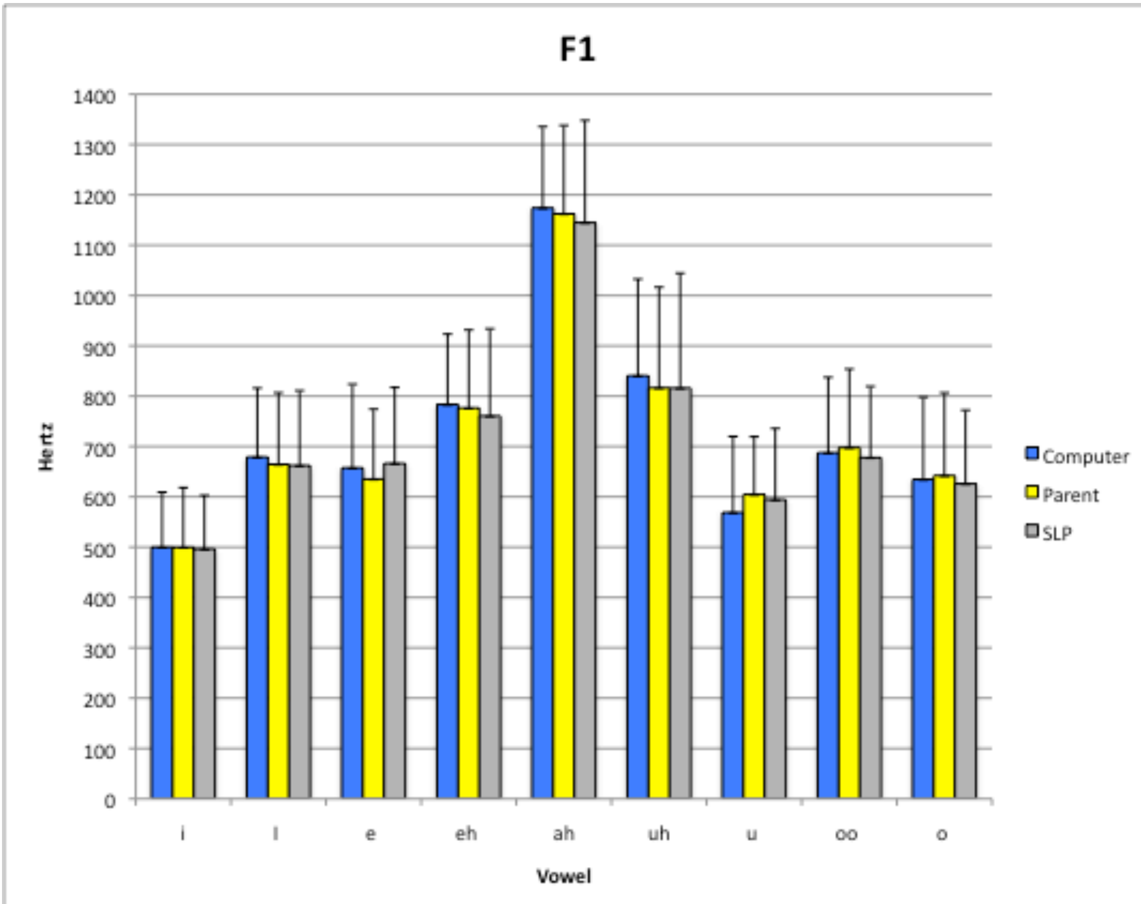
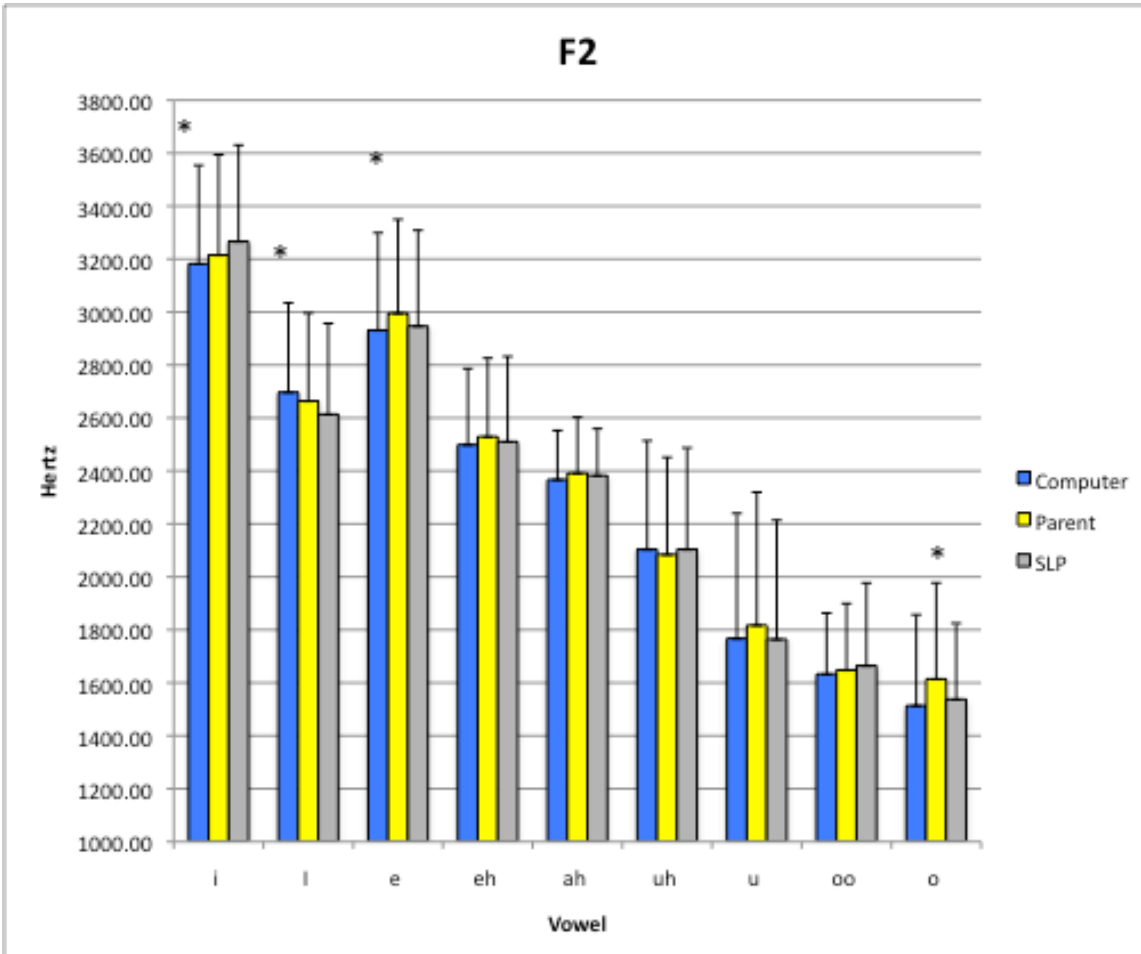


Figure 3.2. F2 values of individual vowels across all conditions.



*Significant

VOT/Final duration of Stops.

Table 3.4 summarizes the data for average VOT and final stop durations for all stops by position in the word across all three conditions. The values of the overall F-test, p-values, MSe, and pairwise follow-ups tests are reported in Table 3.5. Results of VOT across phonemes and word positions are shown in Figure 3.3.

Table 3.4. Means and standard deviations of VOT/Final stop duration for each stop by word position across all three conditions.

	Condition		
Phoneme (position)	Computer	Parent	SLP
/p/ (i)	62.24 (36.78)	57.31 (39.06)	52.86 (49.25)
/p/ (m)	74.20 (23.60)	44.16 (22.82)	53.00 (28.03)
/p/ (f)	13.75 (9.68)	20.22 (15.35)	18.24 (13.38)
/b/ (i)	18.79 (12.76)	17.70 (12.06)	14.80 (8.71)
/b/ (m)	17.92 (7.66)	18.63 (7.66)	20.58 (10.31)
/t/ (i)	83.85 (45.99)	67.13 (39.90)	86.06 (53.18)
/t/ (m)	65.98 (23.51)	40.88 (19.32)	48.88 (16.03)
/t/ (f)	18.52 (11.68)	23.86 (21.87)	25.48 (23.54)
/d/ (i)	22.10 (14.45)	19.82 (10.68)	20.47 (12.15)
/d/ (m)	23.41 (12.31)	24.93 (19.69)	23.10 (12.74)
/d/ (f)	18.90 (8.26)	16.03 (6.13)	20.96 (9.22)
/k/ (i)	74.41 (29.11)	70.26 (31.64)	65.07 (25.27)
/k/ (m)	74.78 (58.74)	57.32 (51.25)	62.96 (44.63)
/k/ (f)	45.07 (57.79)	34.82 (25.74)	38.09 (30.45)
/g/ (i)	27.75 (7.91)	34.37 (18.40)	26.00 (12.78)

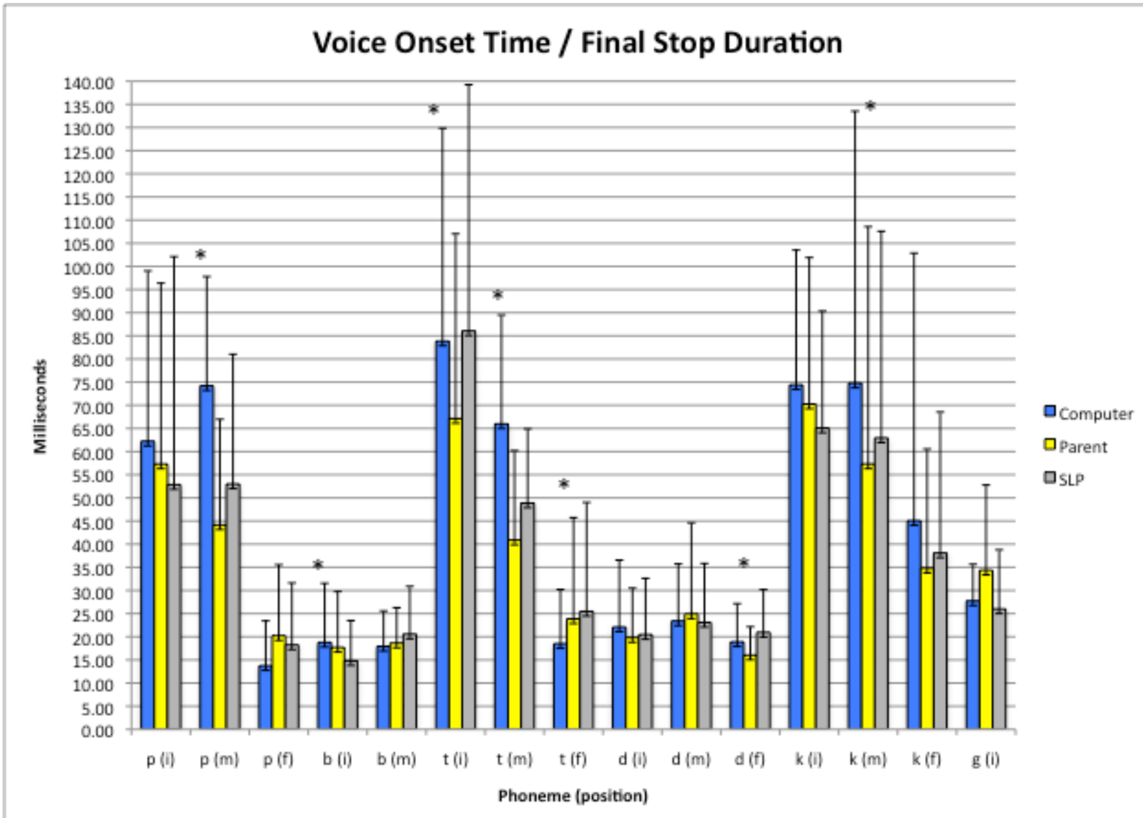
Table 3.5. Overall F-test, P value, mean square error, HSD minimum mean difference value, and significant pairwise follow-up tests for VOT/Final stop duration of all stops by word position.

Phoneme (Position)	*F*	P	MSe	HSDmmd	Significant follow-up tests
/p/ (i)	2.108 (2,284)	0.123	.001		
/p/ (m)	12.199 (2,62)	<.001*	0.001	0.019	Computer vs. Parent; Computer vs. Clinician
/p/ (f)	2.478 (2,64)	.092	.000		
/b/ (i)	6.503 (2, 302)	.002*	.0001	.002	Computer vs. Clinician Parent vs. Clinician
/b/ (m)	0.555 (2,46)	.578	.0001		
/t/ (i)	3.982 (2,122)	.021*	.002	.019	Parent vs. Clinician
/t/ (m)	3.863 (2, 14)	.046*	.0001	.004	Computer vs. Parent**
/t/ (f)	4.412 (2, 224)	.013*	.001	.003	Computer vs. Parent; Computer vs. Clinician
/d/ (i)	1.099 (2, 190)	.335	.000		
/d/ (m)	0.491 (2, 186)	.613	.000		
/d/ (f)	3.427 (2, 76)	.038*	.0007	.004	Parent vs. Clinician
/k/ (i)	3.022 (2, 204)	.051	.001		
/k/ (m)	3.311 (2, 142)	.039*	.002	.017	Computer vs. Parent
/k/ (f)	1.912 (2, 224)	.150	.002		
/g/ (i)	.816 (2, 14)	.462	.000		

*Significant

***Close to reaching significance*

Figure 3.3. Voice onset time/Final stop duration values of individual phonemes by word position across all conditions.



*Significant

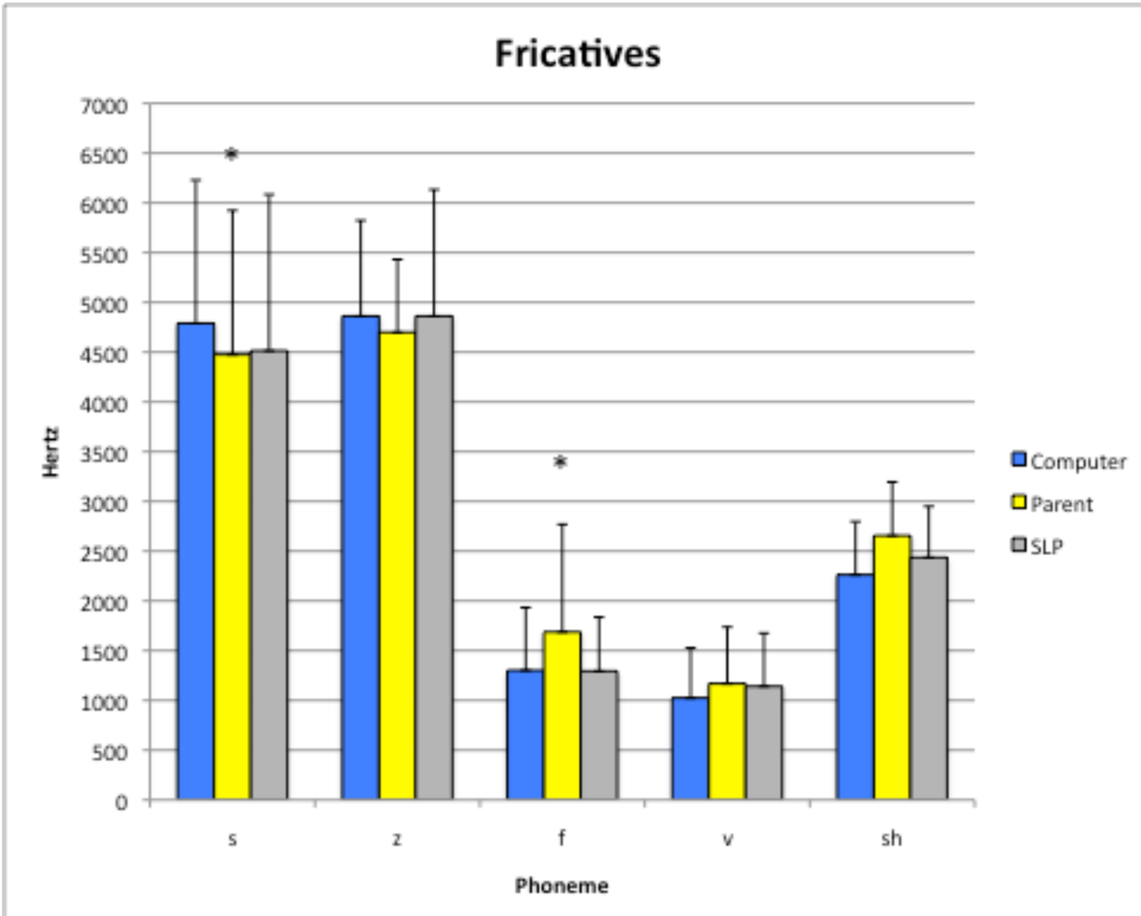
Spectral Base Frequencies of Fricatives.

Table 3.6 summarizes the data for average base spectral frequency for all fricatives across all three conditions. There was a significance difference in base spectral frequency for /s/ across conditions, F (2, 320) = 3.238, p= 0.041, Mse = 1470375.56. Pairwise comparisons using HSD (with a minimum mean difference = 316.321) revealed significant differences only between the computer-led and parent-led conditions. No significance was observed in base spectral frequency for /z/ across conditions, F (2, 78) = 0.579, p = 0.563, Mse = 608493.59. There was a significance difference in base spectral frequency for /f/ across conditions, $F\ (2, 78) = 4.296$, $p= 0.017$, Mse = 470176.29. Pairwise comparisons using HSD (with a minimum mean difference = 368.62) revealed significant differences between the computer-led and parent-led conditions as well as the parent-led and clinician-led conditions, with no difference between the computer-led and clinician-led conditions. . No significance was observed in base spectral frequency for /v/ across conditions, $F\ (2, 94) = 1.388$, $p = 0.255$, Mse = 201842.49. No significance was observed in base spectral frequency for /ʃ/ across conditions, $F\ (2, 30) = 2.282$, $p = 0.120$, Mse = 272930.56. Results of base spectral frequency across phonemes are shown in Figure 3.4.

Table 3.6. Means and standard deviations of base spectral frequency for each fricative across all three conditions.

	Condition		
Phoneme	Computer	Parent	SLP
/ s /	4790.68 (1438.44)	4475.32 (1448.34)	4514.13 (1570.22)
/ z /	4862.50 (960.69)	4700.00 (732.05)	4862.50 (1270.92)
/ f /	1302.50 (631.44)	1687.91 (1081.68)	1294.98 (541.57)
/ v /	1025.00 (502.55)	1168.75 (569.12)	1141.67 (534.29)
/ ʃ /	2262.50 (535.26)	2656.25 (539.10)	2437.50 (512.35)

Figure 3.4. Base spectral frequency values of individual phonemes across all conditions.



*Significant

Coefficient of Variation.

Table 3.7 summarizes the data for COV for each manner of production across all three conditions. Results of COV across manner of production are shown in Figure 3.5. Additionally, results of COV across individual phonemes for vowels (F1 & F2), stops, and fricatives are displayed in Figures 3.6, 3.7, 3.8, and 3.9 respectively.

Table 3.7. Means and standard deviations of coefficient of variation for each manner classification across all three conditions.

	Coefficient of Variation		
	Computer	Parent	SLP
Stops	44.136 (11.45)	49.592 (10.52)	46.251 (7.93
Fricatives	31.020 (11.50)	33.067 (17.02)	32.588 (9.24)
Vowels-F1	15.306 (3.01)	16.211 (3.29)	15.408 (2.12)
Vowels-F2	9.258 (2.53)	9.716 (3.19)	9.379 (2.62)

Figure 3.5. Coefficient of variation values classified by manner of production across all conditions.

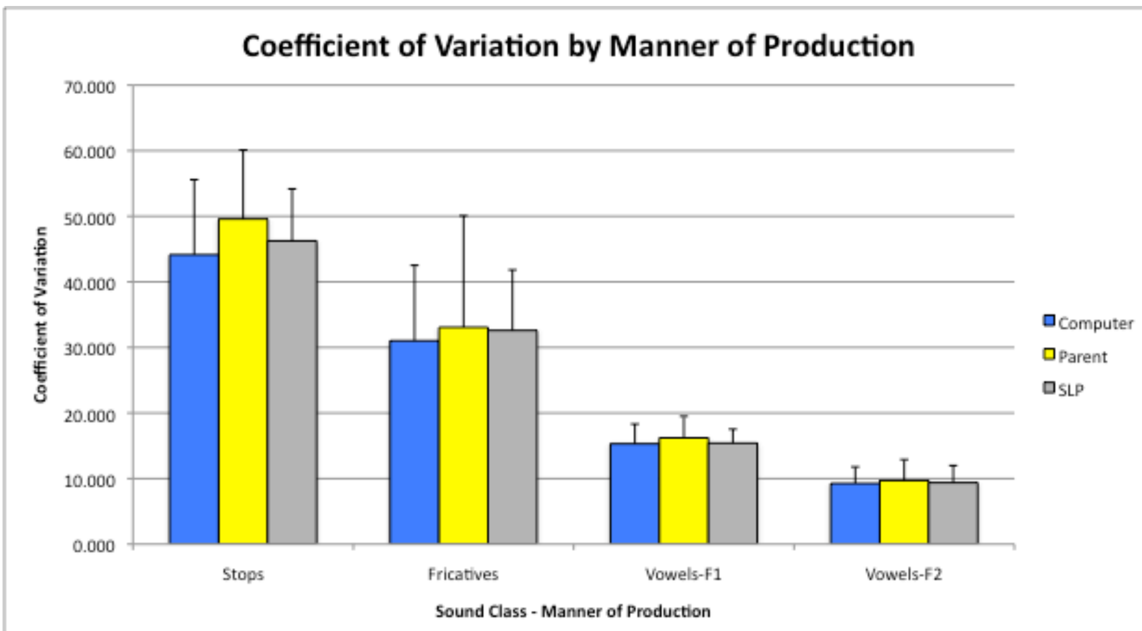


Figure 3.6. Coefficient of variation values for F1 of all vowels across all conditions.

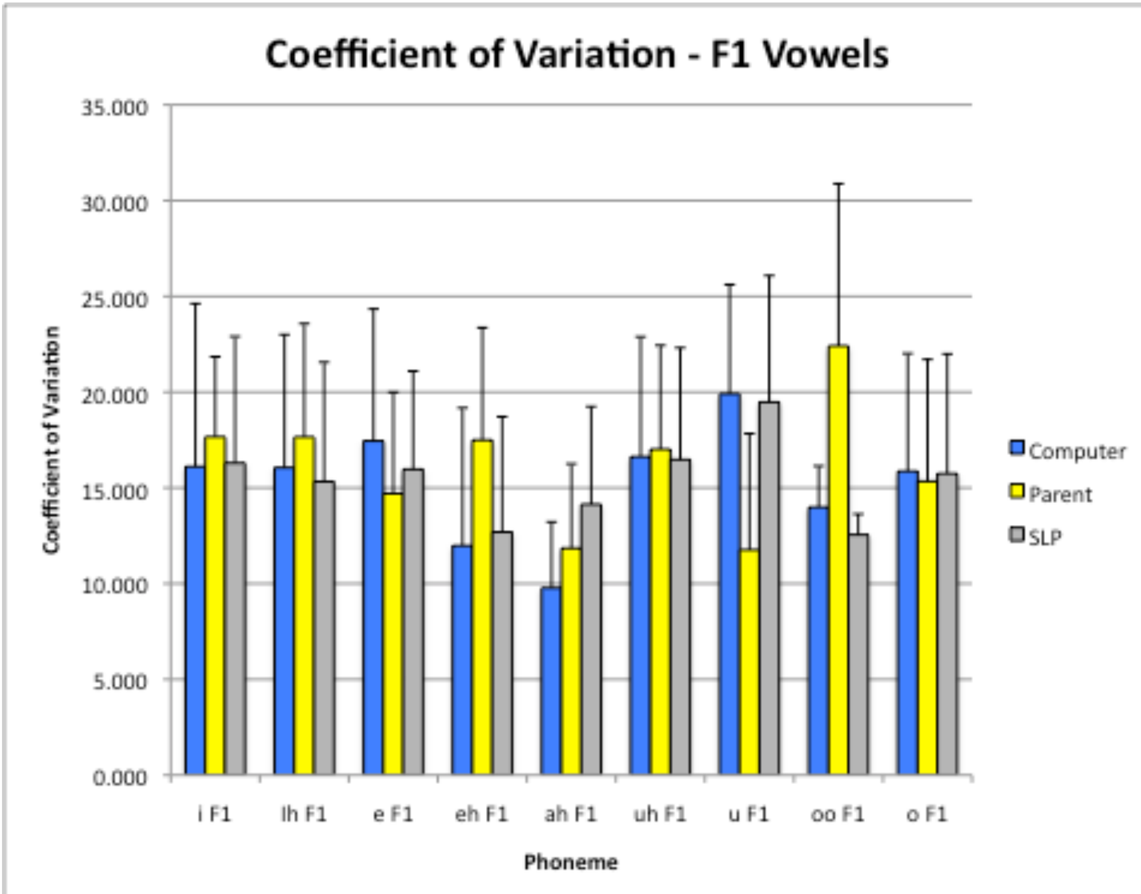


Figure 3.7. *Coefficient of variation values for F2 of all vowels across all conditions.*

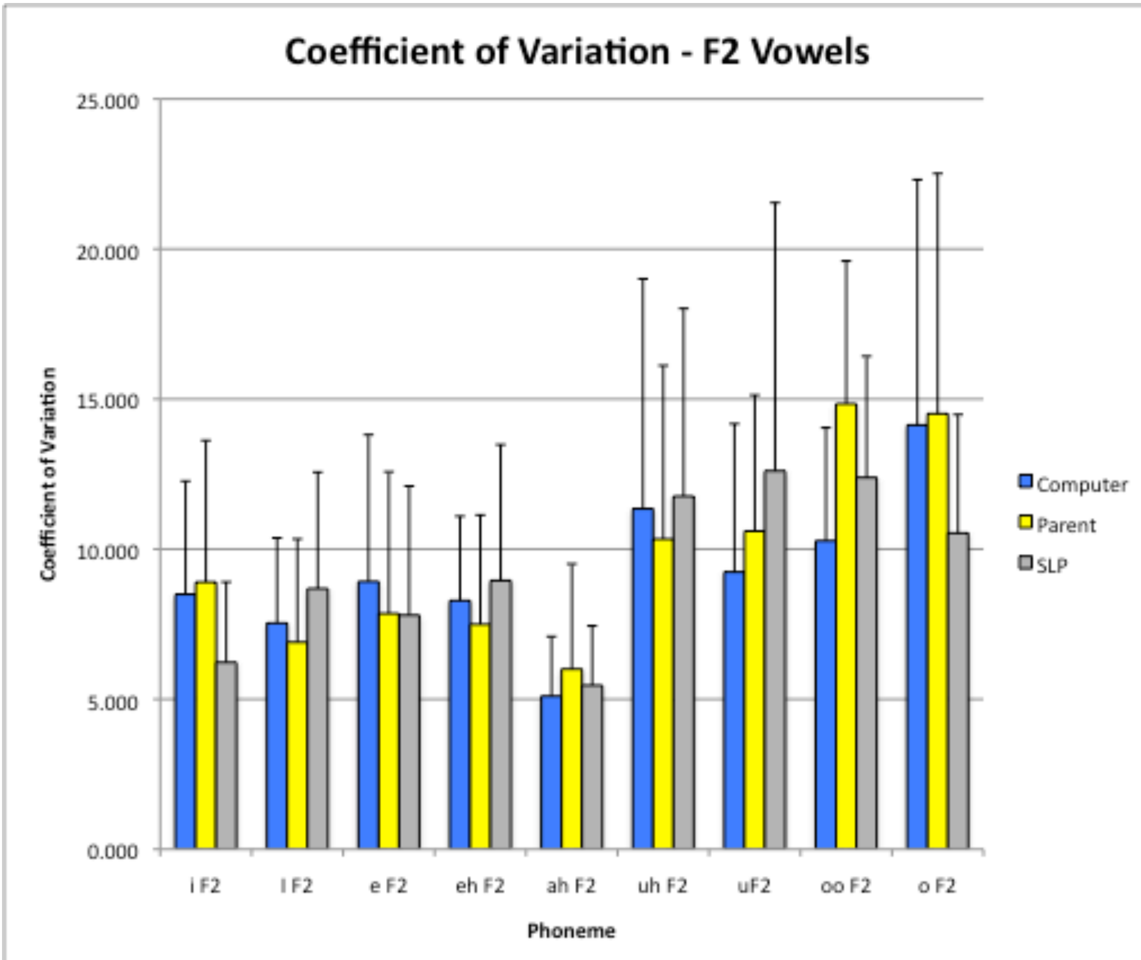


Figure 3.8. Coefficient of variation values for individual stops by word position across all conditions.

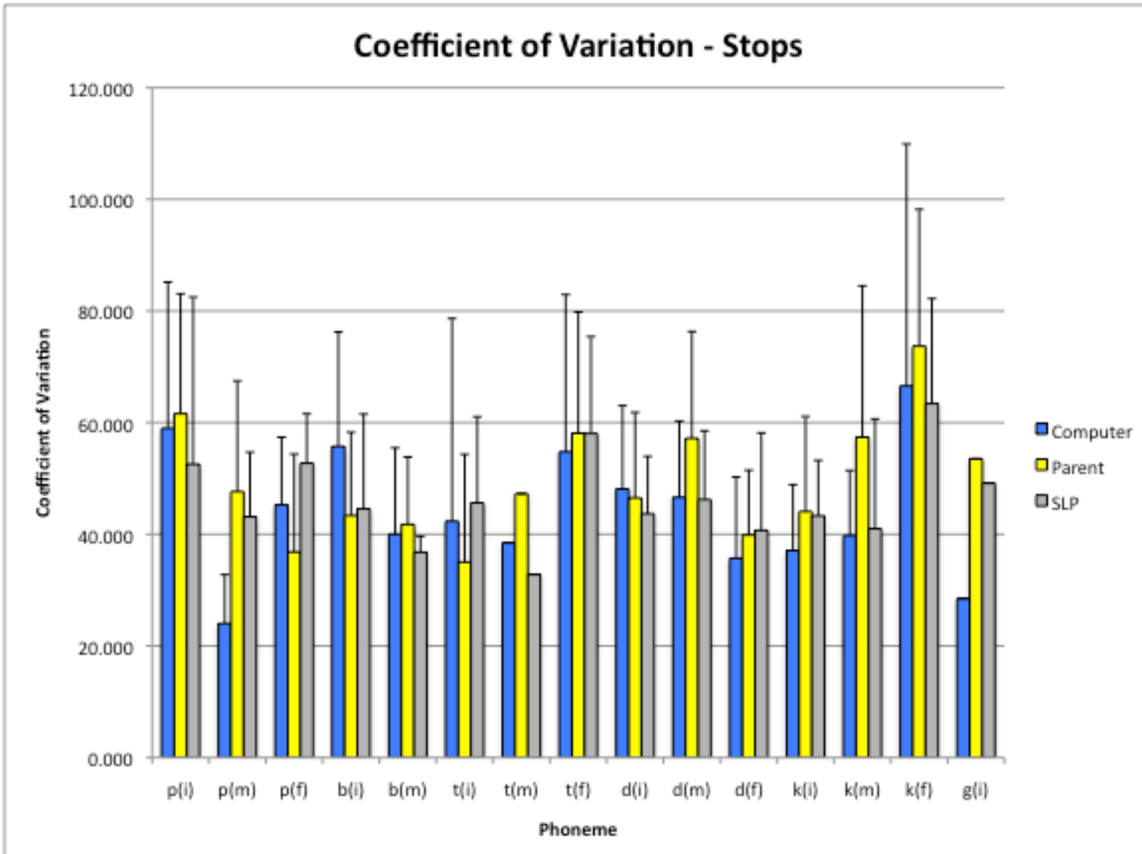
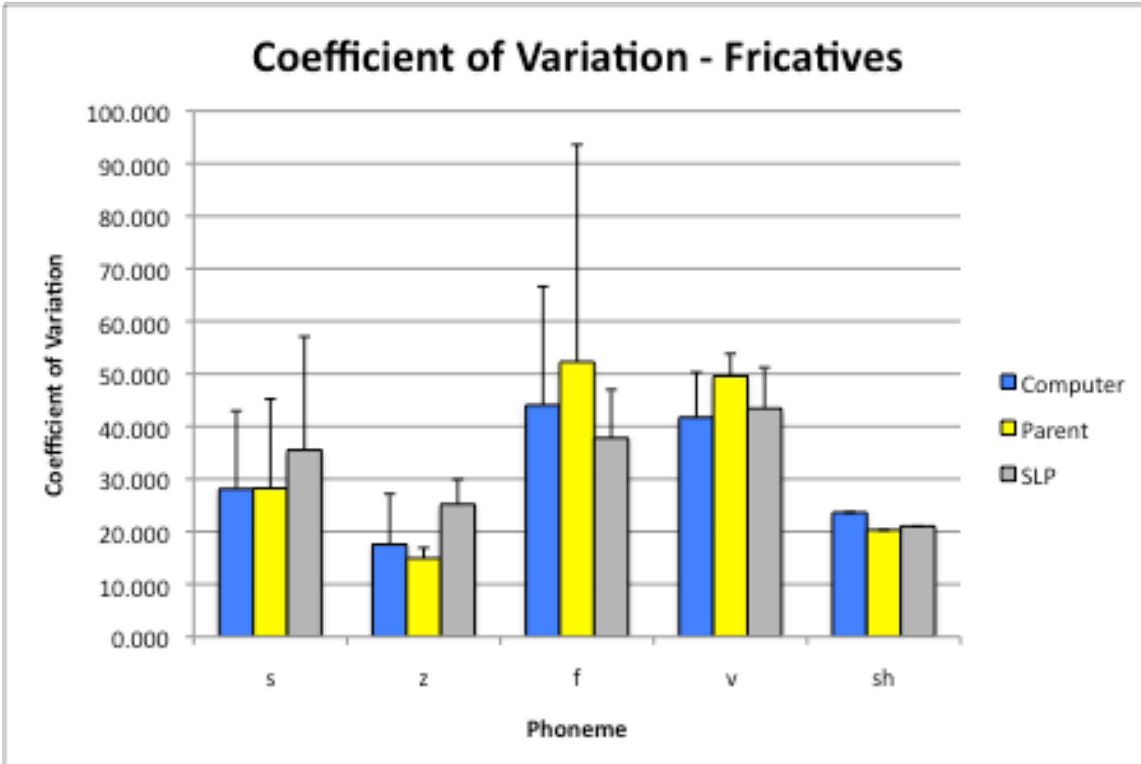


Figure 3.9. Coefficient of variation values for individual fricatives across all conditions



Discussion

We hypothesized that there would be no significant results across conditions. This hypothesis was partially supported by the results. With reference to vowel analysis, there were no significant differences between the F1 of all vowels and the F2 of the vowels / ɛ, æ, ə, u, ʊ /; however, there were significant differences in the F2 of the vowels /i, I, e, o/. F1 reflects tongue height and openness during vowel productions, while F2 reflects the forward and backward position of the tongue. Productions of the vowels / e, o / revealed significant differences between the computer-led practice and parent-led practice, but not computer-led and clinician-led practice or parent-led practice and clinician-led practice. In essence, computer-led practice was more comparable to clinician-led practice for those vowels. However, productions of the vowels / i, I / showed significant differences between the computer-led and clinician-led conditions, but not computer-led and parent-led conditions or parent-led and clinician-led conditions. Therefore, the F2 of vowels /i, I/ more closely matched the clinician-led condition. Overall, this indicates that the computer-led practice led to vowel productions that were comparable to current practice (i.e., parent- or clinician-led practice). Subtle differences were noted in tongue retraction, although no clear pattern was found.

With reference to the analysis of fricatives, the hypothesis again was partially supported. There were no significant differences between the base spectral frequency of the fricatives / z, v, ʃ /; however, there were significant differences in the base spectral frequency of the fricatives / s, f /. Productions of the fricative / s / revealed significant differences only between the computer-led and parent-led practice; however, the base spectral frequency of / s / in the computer-led condition reflected a slightly higher frequency, which reflects a more accurate production (Baken & Orlikoff, 2000). In addition, the fricative / f / displayed significant differences between the computer-led and parent-led conditions and the parent-led and clinician-led conditions, indicating the computer-led and clinician-led conditions were comparable.

With reference to analysis of stops, the hypothesis again was partially supported, although there were more significant differences between conditions with respect to VOT/Final stop duration. There were no significant differences between the VOT/Final stop duration of initial and final /p/, medial /b/, initial and medial /d/, initial and final /k/ and initial /g/. However, there were significant differences in the VOT/Final stop duration of medial /p/, initial /b/, initial, medial, and final /t/, final /d/, and medial /k/. Productions of the medial /p/, and final /t/ revealed significant differences between the computer-led and parent-led conditions and computer-led and clinician-led conditions, but not between the parent-led and clinician-led conditions. Productions of medial /t/ and medial /k/ revealed significant differences between the computer-led and parent-led conditions, and initial /t/ and final /d/ revealed significant differences between the parent-led and clinician-led conditions. Finally, productions of initial /b/ showed significant differences between the computer-led and clinician-led conditions and parent-led and clinician-led conditions, but not computer-led and parent-led conditions. The majority of significant results occurred on voiceless sounds (5) vs. voiced sounds (2). Most importantly, when analyzing VOT/Final stop duration the computer-led condition led to the longest durations in four of the seven phonemes, while the other three displayed the longest durations in the clinician-led condition. The parent-led condition led to the shortest durations for five of the seven phonemes. It was informally noted during the study, that the participants moved more quickly through their practice words in the parent-led conditions, while the computer-led condition took longer due to a steady automatic pace. When these results are aligned with the results of the perceptual accuracy (Chapter 2), the biggest discrepancy in accurate productions of stops occurred on /k, g/ with the lowest accuracy in the parent-led condition. It is possible that the increase in VOT/Final stop durations led to more accurate productions in the computer-led condition.

When descriptively analyzing the mean COV, the greatest variability occurred in the parent-led condition across all manners of production. When COV was computed across individual phonemes, the results were consistent. For F1 and F2 of all vowels, the parent-led condition had the greatest variability nine times, the clinician-led condition five times, and the computer-led condition four times. For stops, the parent-led condition had the greatest variability ten times, the clinician-led condition three times, and the computer-led condition two times. For fricatives, the parent-led condition had the greatest variability two times, the clinician-led condition two times, and the computer-led condition one time.

Overall, individually developed computer-led practice appears to be a viable option for accurate practice for children with CAS. Past results have revealed that children were motivated by computer-led practice, it led to increased quantity of practice, and perceptual accuracy remained consistent with current practice. Current acoustic results revealed comparable acoustic measures compared to current practice, increased VOTs and final stop durations that appeared to lead to increased accuracy, and the least amount of variability across all conditions. Increased motivation and quantity of practice combined with maintaining accurate speech productions, with a few measures leading to increased accuracy, leads to a combination of factors that appear to provide the support for effective, computer-led speech production practice for children with CAS. Due to their need for intense, individualized therapy and practice, computer-led speech practice may provide the extra support they need to improve their speech production.

Limitations

One limitation of this study is that the computer-led practice condition was automatically paced for participants, while the parent-led and clinician-led conditions were allowed to move at their own pace. Although the accuracy of stops appeared to be higher in the computer-led condition, the slower pace, versus type of practice condition, made have accounted for some of the differences reported.

A second limitation was target words were different for each participant, which could have led to subtle differences in acoustic measures. However, the target words were of the same accuracy level (40-80% accurate) to each individual participant. Using a consistent target set across participants would have likely led to targets that were too easy for some and too challenging for others, likely resulting in ceiling and floor effects. Choosing words that reflect a consistent accuracy level placed all participants on a similar "playing field." In addition, this more accurately reflects the practice needs for children with CAS, which in turn can have a direct impact on their treatment.

Conclusion

In this study, the researcher attempted to determine if computer-led speech practice was a viable independent practice program for children with CAS by comparing the acoustical accuracy of speech in computer-led practice to two common practices, clinician-led and parent-led practice. Computer-led practice led to speech production that was equally as accurate and less variable compared to speech production in clinician-led and parent-led conditions, and at times led to increased accuracy, including more precise fricatives and lengthened VOTs and final stop durations. Compiled with previous results indicating computer-led speech practice led to a greater quantity of practice, was preferred to other practice options (Nordness & Beukelman, 2010), and comparable perceptual accuracy (see chapter 2), accurate speech production during computer-led speech practice establishes computer-led speech practice as an appropriate practice tool for children with CAS.

CHAPTER 4: CONCLUSIONS

Due to the reported need for intensive practice for children with CAS (ASHA, 2007; Edeal & Gildersleeve-Neumann, in press; Maas et al., 2008), adherence to a practice program is necessary (Behrman et al., 2008; Nordness & Beukelman, 2010). Computer-led practice led to increased motivation and attention, elicitation of successful practice, greater quantity of practice, and was preferred over parent-led practice (Choe et al., 2007; Clendon et al., 2003; Nelson & Masterson, 1999; Nordness & Beukelman, 2010; Shriberg et al., 1989; Shriberg et al., 1990). However, the accuracy of speech productions during independent practice has not been studied and speech productions must be accurate to establish an accurate motor plan (Maas et al., 2008; Schmidt, 1975).

This investigation examined speech accuracy of children with CAS during three speech practice conditions (i.e., computer-led, parent-led, and clinician-led conditions) by a) comparing the perceptual accuracy of speech, b) comparing the acoustical accuracy of stops, vowels, and fricatives, and c) comparing the variability of stops, vowels, and fricatives.

The first study evaluated the children's accuracy of speech perceptually across conditions using the PCC and PVC. Results revealed no significant differences between perceptual accuracy of consonants and vowels during the three practice conditions; therefore, computer-led practice led to speech productions that were as accurate as current practice. Additionally, speech productions in the computer-led condition led to greater precision in back sounds and fewer out-of-class substitutions and deletion errors compared to the parent-led and clinician-led conditions.

The second study evaluated the children's accuracy of speech across conditions in greater detail using acoustic measurements, including VOT/final duration of stops, F1 and F2 of vowels, base spectral frequency of fricatives, and variability across all acoustic measurements. Vowel productions were consistent across all three conditions with the exception of subtle differences in the F2 of the vowels / i, I, e, o /, which revealed no consistent pattern. Production of the fricatives / z, v, ʃ / were consistent across all three conditions, but productions of / s, f / revealed greater accuracy in the computer- and clinician-led condition compared to the parent-led condition. There were no significant differences in over half of the stop productions. The majority of significant results occurred on voiceless sounds and the computer- and clinician-led condition led to the longest durations while the parent-led condition led to the shortest durations. It appeared the lengthened durations in the computer- and clinician-led conditions might have led to increased accuracy when compared to the perceptual results in the first study. Overall, the greatest variability occurred in the parent-led condition across all manners of production, followed by the clinician-led condition, and the computer-led condition revealed the least variability.

Limitations

One limitation of this study is that the computer-led practice condition was automatically paced for participants, while the parent-led and clinician-led conditions were allowed to move at their own pace. Although the accuracy of stops appeared to be higher in the computer-led condition, the slower pace, versus type of practice condition, made have accounted for some of the difference.

A second limitation was target words were different for each participant, which could have led to subtle differences in perceptual and acoustic measures. However, the target words were of the same accuracy level (40-80% accurate) for each individual participant. Using a consistent target set across participants would have likely led to targets that were too easy for some and too challenging for others, likely resulting in ceiling and floor effects. Choosing words that reflect a consistent accuracy level placed all participants on a similar "playing field." In addition, this more accurately reflects the practice needs for children with CAS, which in turn can have a direct impact on their treatment.

A final limitation was interrater reliability was not conducted on the acoustic analysis due to the difficulty level of the task; however, this is common practice in acoustic measurement. Although no intrarater reliability check was completed, the primary researcher was trained in a reliable manner as evidenced by acoustic scoring training with a member of the researcher's dissertation committee, Dr. Tom Carrell, an expert in the field of acoustics, and completed frequent recalibration to the measurements with Dr. Carrell throughout the duration of the dissertation.

Future Directions

The results of this dissertation revealed computer-led speech practice led to accurate speech productions for children with CAS; therefore, it is a viable tool to provide additional practice needed to improve speech intelligibility over time. In the future, research should examine the benefit of utilizing computer-led speech practice in combination with speech therapy compared to therapy alone to determine the added benefit of speech practice. Additionally, further research is needed to determine the ideal amount of practice to maximize gains in speech intelligibility and to analyze the effect of lengthened voice onset times on learning of stop consonants. Additional research to examine the effect of animations in computer-led practice as well as the impact of a consistent versus a variable auditory model during speech practice is warranted based on the results of this dissertation.

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Appendix A

Parental Consent Form

Parental/Legal Guardian Informed Consent Form

Title of This Research Study

A CLINICAL TREATMENT PROGRAM FOR PERSONS WITH APRAXIA OF SPEECH

Invitation

Your child, ____, is invited to participate in this research study. The following is provided in order to help you decide whether to allow your child to participate. If you have any questions, please do not hesitate to ask.

Why is your child being asked to be in this research study?

Your child is eligible to participate in this study because he/she has been identified as a child with suspected childhood apraxia of speech (CAS).

What is the reason for doing this research study?

The purpose of this study is to determine how effective a particular type of speech therapy, motor learning therapy, is with persons with apraxia of speech by varying the amount of reinforcement, varying level of cueing support provided by the speech-language pathologist (SLP), varying the complexity of the targets, and varying the medium of practice. Speech therapy for persons with apraxia of speech often takes numerous years and this study will attempt to help children make more rapid progress with better outcomes. A second purpose is to enhance the speech, language, and overall communication of individuals with severe CAS through augmentative and alternative communication (AAC).

What will be done during this research study?

As you know, your child has been in an intervention program for their speech difficulties. In order to study the impact of this intervention program on a number of people, including your child, we need your permission to analyze your child's speech performance. In this study, your child will complete speech and language testing and therapy just as have been done in the clinic up until now. Specific procedures may include the following: (a) production of speech sounds, (b) completion of speech practice in face-to-face and computer scenarios, (c) communication interactions, (d) use of high and low tech device to support speech, (e) understanding and use of language. In addition, your child will complete a test to determine how understandable he/she is when saying individual words and also in conversation.

Your child will continue to be seen for regularly scheduled speech therapy sessions weekly. Although frequency and length of session is determined based on the child's needs, it is frequently 3 - 4 times per week for approximately 20 minutes. You will often be provided with a homework task to complete with your child daily for 5 - 10 minutes. This research project will continue until your child is dismissed from the therapy program (due to progress, going to a different program, or you decide you no longer wish for your child to participate). Because children with CAS tend to require lengthy speech intervention, your child may continue to be enrolled in speech therapy for 8 or more years. Our intent with this research study is to decrease this time significantly and result in your child requiring only 2-3 years of therapy.

During therapy, your child will be told specific information after he/she speaks. Sometimes, your child will be told about the result of his/her speech, such as "I heard you say *pop*." At other times, your child will be told about his/her performance, such as "You put your lips together when you said that." Sometimes, your child may not be told anything at all. Your child will also practice speech targets at varying difficulty levels (e.g., words, phrases, etc.), while being provided different level of cueing support by the SLP (e.g., visual cues, auditory cues, etc.), and varying the medium of practice (e.g., practice with the clinician, a computer, etc.). Your child may also practice using other ways to communicate when speech breaks down (e.g., sign, high-tech and low-tech devices). The researchers will measure the accuracy of your child's speech productions, how well they use language, and how well they communicate. In addition, we will audiotape and videotape therapy so that we may complete analysis of your child's speech productions and progress. These videotapes will be securely retained for three years after data collection on the project is completed. The researchers will complete all data interpretation and analysis.

What are the possible risks of being in this research study?

There are no known risks or discomforts your child could experience during this study. No risk or discomfort has previously been documented associated with any of these measures. Participation will require your child to interact in speech therapy for frequent sessions of approximately 20 minutes in duration, completing the tasks as usual.

What are the possible benefits to your child?

The use of this type of speech therapy may help your child to achieve faster progress in speech therapy with skills that may transfer to other words and situations. Although we anticipate more effective progress and outcomes, it is possible that there may be no direct benefit to your child from participating in this study.

What are the possible benefits to other people?

The knowledge gained from this study may be of value to others diagnosed with apraxia of speech and to professionals who work with them because it will provide information about designing treatment programs and determining the best ways to treat speech sound disorders in persons with apraxia of speech. This information is currently unavailable.

What are the alternatives to being in this research study?

If you decide not to allow your child to participate in this study, he/she will continue in regularly scheduled speech therapy using conventional methods. This will involve standard assessments without data collection for research purposes.

What will your child being in this research study cost you?

There is no cost to you to be in this research study. However, you or your insurance company will still be responsible for assessments/treatments conducted as part of standard clinical care

Will you or your child be paid for being in this research study?

Your child will not be paid to be in this research study.

Who is paying for this research?

This research is being paid for in part by grant funds from the Munroe-Meyer Guild and in part by the Department of Speech Pathology at Munroe-Meyer Institute of the University of Nebraska Medical Center.

What should you do if your child is injured or has a medical problem during this research study?

If your child has a research-related injury or problem, or if your child experiences an adverse reaction, please immediately contact one of the investigators listed at the end of this consent form.

How will information about your child be protected?

Your child has rights regarding the privacy of his/her medical information collected prior to and in the course of this research. This medical information, called "protected health information" (PHI), includes demographic information, the results of physical exams, blood tests, x-rays and other diagnostic and medical procedures, as well as his/her medical history. You have the right to limit the use and sharing of your child's PHI, and you have the right to see your child's medical records and know who else is seeing them.

By signing this consent form, you are allowing the research team to have access to your child's PHI. The research team includes the investigators listed on this consent form and other personnel involved in this specific study at UNMC. For subjects enrolling at Madonna Rehabilitation Hospital, you will also be asked to sign a HIPPA Authorization Form.

Your child's PHI will be used only for the purpose(s) described in the section "What is the purpose of this study?"

Your child's PHI will be shared, as necessary, with the Institutional Review Board (IRB) and with any person or agency required by law. You are also allowing the research team to share your PHI with other people or groups listed below. All of these persons or groups are obligated to protect your PHI.

Susan Fager, Ph.D., Madonna Rehabilitation Hospital

You are authorizing us to use and disclose your child's PHI for as long as the research study is being conducted. There is currently no plan to end this study, so your child's information may be kept and used for as long as the study is being conducted.

You may cancel this authorization to use and share your child's PHI at any time by contacting the principal investigator in writing. If you cancel this authorization, your child may no longer participate in this research. If you cancel this authorization, use or sharing of future PHI will be stopped. The PHI that has already been collected may still be used.

The results of clinical tests and therapy performed as part of this research may be included in your child's medical record. The information from this study may be published in scientific journals or presented at scientific meetings but your child's identity will be kept strictly confidential.

What are your child's rights as a research subject?

Your child has rights as a research subject. These rights are explained in this consent form and in *The Rights of Research Subjects* that you have been given. If you have any questions concerning your child's rights or complaints about the research, talk to the investigator or contact the Institutional Review Board (IRB) by telephone (402) 559-6463, e-mail: IRBORA@unmc.edu, or mail: UNMC Institutional Review Board, 987830 Nebraska Medical Center, Omaha, NE 68198-7830

What will happen if you decide not to allow your child to be in this research study?

You can decide not to allow your child to be in this research study. Deciding to not allow your child to be in this research study will not affect your child's medical care or you or your child's relationship with the investigator(s), the University of Nebraska Medical Center or The Nebraska Medical Center. Your child's doctor will still take care of your child and your child will not lose any benefits to which he/she is entitled.

What will happen if you decide to have your child stop participating once he/she has started?

You can stop being in this research study ("withdraw") at any time before, during, or after the treatment begins. Your child's doctor will still take care of you though your child may not be able to get the research treatment. Deciding to withdraw will otherwise not affect your child's care or you or your child's relationship with the investigator(s), the University of Nebraska Medical Center or The Nebraska Medical Center. You will not lose any benefits to which you are entitled.

For your safety, please talk to the research team before you stop any research treatments. They will advise you how to stop your child's treatments most safely. If you withdraw your child, your child may be asked to undergo some additional tests. You do NOT have to agree to do these tests.

Your child may be taken off the study if you don't follow instructions of the investigator(s) or the research team.

If the research team gets any new information during this research study that may affect whether you would want your child to continue being in the study you will be informed promptly.

Documentation of Informed Consent

You are freely making a decision whether to allow your child to be in this research study. Signing this form means that (1) you have read and understood this consent form, (2) you have had the consent form explained to you, (3) you have had your questions answered, and (4) you have decided to allow your child to be in the research study.

If you have any questions during the study, you should talk to one of the investigators listed below. You will be given a copy of this consent form to keep.

________________________________	________________	__________
Signature of Parent/Legal Guardian	Date	Time

____

Printed Name

________________________________	________________________________
Signature of Participant (7-18 years of age)	Printed Name

Although no additional studies are planned at this time, you may be contacted for participation in future studies at a later date, for example by telephone and/or by mail. Please initial below:

______ I agree to be contacted for participation in future studies.

______ I do not agree to be contacted for participation in future studies.

I CERTIFY THAT ALL THE ELEMENTS OF INFORMED CONSENT DESCRIBED ON THIS CONSENT FORM HAVE BEEN EXPLAINED FULLY TO THE PARENT. IN MY JUDGEMENT, THE PARENT IS VOLUNTARILY AND KNOWINGLY GIVING INFORMED CONSENT AND POSSESSES THE LEGAL CAPACITY TO GIVE INFORMED CONSENT TO PARTICIPATE IN THIS RESEARCH STUDY.

________________________________	________________
Signature of Person Obtaining Consent	Date

AUTHORIZED STUDY PERSONNEL

PRINCIPAL INVESTIGATOR:	Marsha D. Sullivan, M.S.	Phone: (402) 559-6460
SECONDARY INVESTIGATORS:	Amy Nordness, Ph.C.	Phone: (402) 559-6460
	Susan Fager, Ph.D.	Phone: (402) 483-9459
	Korey Stading, M.S.	Phone: (402) 559-6263
	Bethany Hughes, M.S.	Phone: (402) 559-6460

APPENDIX B

Youth Information Sheet

TITLE: **A CLINICAL TREATMENT PROGRAM FOR PERSONS WITH APRAXIA OF SPEECH**

YOUTH INFORMATION SHEET

You are invited to be in this research study. Being in this research study is voluntary – you don't have to be in this research study to get treated. If you decide not to be in the study your speech therapist and doctor will still take care of you.

The goal of this study is to find out if there are better ways to do therapy to help persons with apraxia make better progress.

As part of this study, you will participate in speech therapy 3 or 4 times a week for 2-3 years. Your therapist will give you information after you say something in therapy (sounds, words, sentences, or conversation). Sometimes, she may tell you about the result of your speech, such as "I heard pop." At other times, she may tell you about your performance, such as "You put your lips together." Sometimes, she may not say anything at all. Your therapist will also have you practice words that may be short and long and give you clues with pictures and sounds to help you practice. You may practice in different ways, such as on the computer or with an adult. If you still find it hard to talk, you may practice using books, gestures, or computers to help you talk to others.

We will also get some medical information from your records and hospital chart.

There are no known risks or discomforts from doing this study. You will be in speech therapy, completing the tasks as usual.

APPENDIX C

Child Information Sheet

TITLE: **A CLINICAL TREATMENT PROGRAM FOR PERSONS WITH APRAXIA OF SPEECH**

CHILD INFORMATION SHEET

We are asking you to be in a research study. You don't have to be in this research study to get treated. If you don't want to be in the study your speech therapist and doctor will still take care of you.

The goal of this study is to find out how well speech therapy can help you and other people with the same kind of speech problems to get better.

You will be told about your speech. Sometimes your speech therapist will tell you what you said, like "I heard pop." Sometimes she will tell you what you did, like "You put your lips together." Sometimes she may not say anything at all. Your therapist will also have you practice words that may be short and long and give you clues with pictures and sounds to help you practice. You may practice on the computer or with an adult. If you still find it hard to talk, you may practice using books, gestures, or computers to help you talk to others.

We will also get some medical information from your records and hospital chart.

There is nothing that will hurt. You will be in speech therapy just as you are now.